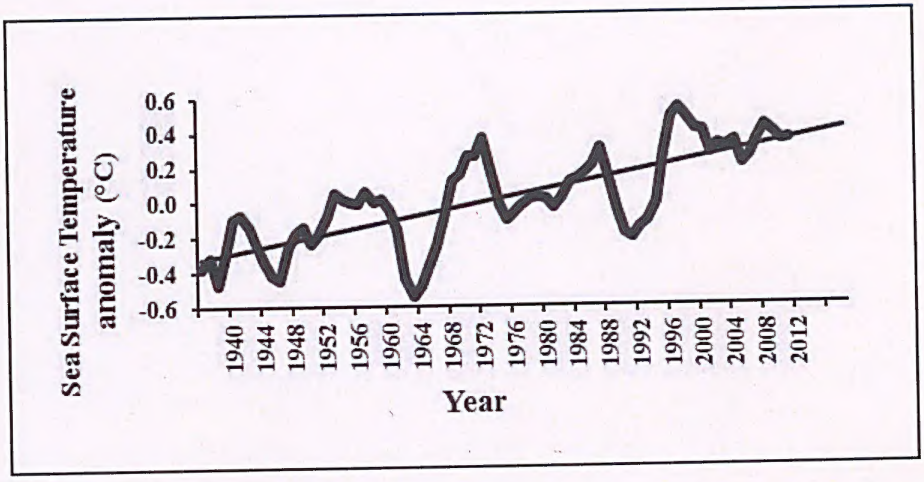
PROCEEDINGS OF THE ROYAL SOCIETY OF QUEENSLAND



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MUSEUM VICTORIA
14 FEB 2017

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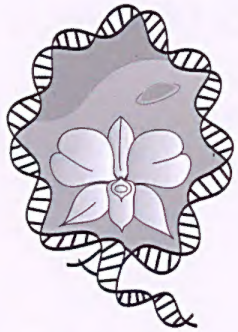

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COVER ILLUSTRATION
Details of the cover illustration are provided in the Editorial.

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EDITORIAL

Climate change is currently the most compelling issue for science, not just for Queensland but the whole world. The scientific literature is saturated with publications on the status, causes and impacts of climate change, and new journals have been established to solely cater for these subjects. Training in scientific research teaches us to critically evaluate our own research and the findings of others – and not to be blindly swayed. I regard the discussions and differing opinions around climate change to be very positive from a scientific viewpoint, and these discussions should be encouraged as we move forward.

In Queensland scientists have witnessed in the summer of 2015-6 an extremely high level of coral bleaching on the Great Barrier Reef caused by some of the highest temperatures ever recorded. There are considerable data to show that temperatures are increasing. An example is time-series data on water temperature off the Queensland east coast compiled by the Australian Bureau of Meteorology, and available from the ABM website. The graph on the cover of this volume plots the Sea Surface Temperature (SST) from 1937 to 2014, and shows an increase in the running mean SST over time. The international standard is to calculate the SST temperature anomaly using the average temperature 1961 to 1990 as the base.

Biota other than corals will also be impacted by changing climate in Queensland. My research in 2016 shows that one of the Queensland fish species taken in coastal fisheries is undergoing a southward range-shift as a result of increasing water temperature since 1975. (Pollock, B. R. 'Latitudinal change in the distribution of luderick *Girella tricuspidata* (Pisces: Girellidae) associated with increasing coastal water temperature in eastern Australia'. *Marine and Freshwater Research.* (2016) 67 pages to be assigned. The challenge now is how to mitigate and manage the effects of climate change in a way that has widespread public support, and our elected representatives will have a key-role in this.

On another issue, peer review is a fundamental requirement for publication in scientific journals. This process provides confidence in the findings described in such publications. During my time as editor of the *Proceedings of the Royal Society of Queensland* many referees with expertise in the relevant subject areas have kindly accepted my invitations to review submitted papers. In all cases these referees have provided extensive commentaries on the submissions, and recommendations regarding publication. For these efforts by referees I express my sincere thanks as well as the gratitude of the Royal Society of Queensland. Some submitted papers have been rejected as they do not meet the required standards. To those authors I suggest that you please regard this as a learning process with much to be gained from comments provided by peer review – and an opportunity to improve on future submissions.

Barry Pollock

ENVIRONMENTAL WATER ASSESSMENT FOR WATER RESOURCE PLANS IN QUEENSLAND

CHOY, S.C.

Water allocation in Queensland's is carried out through a statutory water resource planning process administered under the Water Act 2000. A Water Resource Plan provides the framework for this water allocation that is sustainable and secure for consumptive and non-consumptive uses as well as providing water necessary to sustain the inland and estuarine aquatic environment, including both surface water and groundwater dependent ecosystems. This paper describes Queensland's current approach to assessing environmental water allocations that is based on risk assessment, ecological modelling and the evaluation of different water resource management scenarios. The current approach is a refinement of the previous method that was based on a similar type of risk assessment termed the "Benchmarking Methodology" and is part of an on-going Adaptive Management Strategy which implements on-going improvements in monitoring, evaluation and adjustment of environmental water management based on at least 10-year reviews of Water Resource Plans. For the risk assessment, environmental values and their associated ecological assets to be protected are identified and prioritised. The prioritisation of the assets is based on their critical links to flow and how these links may be affected by different water allocation and management scenarios. Examples from the different Water Plan areas are provided to illustrate the results.

Satish C. Choy (satish.choy@griffith.edu.au), Australian Rivers Institute, Griffith University, Brisbane QLD 4011, Australia.

INTRODUCTION

Water allocation in Queensland is carried out through water resource planning which is a statutory process administered under the *Water Act 2000* (the Act) and is part of the state's commitment to the national water reform agenda signed by the Council of Australian Governments (COAG) in 1994 and the National Water Initiative of 2004. The objective of these agreements is to ensure resource availability is properly assessed, with supplies sustainably allocated to support economic, social and environmental needs. A Water Resource Plan (WRP) provides the framework for sustainable and secure allocation of water for consumptive and non-consumptive uses as well as providing water necessary to sustain the aquatic environment, including surface freshwater, groundwater and estuarine dependent ecosystems. The framework defines water availability, priorities of water use, management strategies, performance indicators, and monitoring and reporting requirements that apply for the life of the Plan, which currently is 10 years. However, Plans can be amended or reviewed before this statutory lifetime on a needs basis.

Hydrologic, socioeconomic and environmental assessments are required under the Act to inform the development of a Draft Water Resource Plan. Water Resource Plans were first implemented in Queensland in about 1999 and each Plan had a statutory life span of 10 years, after which each Plan had to be reviewed and updated. These first generation (Gen 1) Plans started to expire in about 2008 and since then the second generation (Gen 2) Plans have been developed. For the Gen 1 Water Resource Plans, a panel of scientific and technical experts (Technical Advisory Panel) was engaged to carry out the environmental assessments. These assessments were based on the "Benchmarking Methodology" which assessed the ecological "condition" of the various components of the aquatic ecosystem (such as geomorphology, riparian vegetation, freshwater and estuarine fish, invertebrates, aquatic vegetation and water quality) and generally did not explicitly separate the effects of changes in flow regime from other confounding factors, mainly because of the lack of field studies, published data and associated information (Brizga et al., 2002). The assessments adopted an Adaptive Management Strategy, which was to learn from applying an appropriate methodology, in this case, the Benchmarking Methodology, learning from its experience and improving on it through monitoring, new data collection, targeted research and evaluation, and adjustment of environmental water management based on at least 10-year reviews of each Water Resource Plan. The Benchmarking Methodology was refined for Gen 2 Plans, incorporating relevant

new scientific and monitoring data and information collected over the 10-year life of the Plan, identified ecological values, their associated ecological assets and assessed risks to those assets that had critical links to flow, thereby removing or minimising the effects of other confounding factors (e.g. land use). This "critical flow" framework for the Gen 2 Plans was developed and implemented by Queensland Government scientists and the overall approach and each assessment to date have been externally peer reviewed. For further information see https://www.dnrm.qld.gov.au/water/catchments-planning.

To date, the Burnett Basin, Fitzroy Basin, Boyne River, Barron River and some of the Murray-Darling Basin rivers (Warrego, Paroo, Bulloo and Nebine) have had the Gen 1 Environmental Assessments and WRPs reviewed and Gen 2 Environmental Assessments completed. It is still too early to tell if the outcomes of Gen 2 Plans will be better achieved using the Gen 2 Environmental Assessments compared to that of the Gen 1 Environmental Assessments. However, improvements have already been recognised and implemented, as indicated by the Burnett Basin example in TABLE 1.

The environmental water assessment is based on a comprehensive study which provides a flow related risk assessment of the surface freshwater, groundwater and estuarine dependent ecosystems in the WRP area. Based on the ecological asset identification and subsequent analysis of their flow requirements, the risk assessment uses ecological modelling to predict possible impacts to flow and dependent ecosystems from water allocation and management scenarios.

Predicting potential ecological responses to altered flow or groundwater regimes is often complicated by complex interactions between the water regimes and ecosystem components and processes at multiple scales. This complexity is further exacerbated by the confounding effects of other non-flow related stressors present in the system (e.g. land use, toxicants, exotic species, etc.). Consequently, generally applicable measures of ecological responses to managed water regimes are rarely observed or hampered by our incomplete understanding of flow-ecology relationships (Arthington et al., 2006; Kennard et al., 2009; Poff & Zimmerman, 2010; Arthington, 2012; Warfe et al., 2014). Therefore, a practical approach for managing water regimes for specific ecological outcomes requires identifying and partitioning the critical flow or groundwater dependencies of ecosystem components and processes and consideration of their specific water requirements over time. Known as "ecological assets", they are highly valued components of the ecosystem for which aspects of the flow or groundwater regime (i.e. duration, timing, variability, predictability, magnitude, rate of rise and fall) are critical to support their long term viability. These assets are prioritised based on stakeholder input.

The environmental assessment uses an eco-hydraulic modelling approach, based on the principles of ecological risk assessment (ERA) as in the Australian Standards (AS/NZS, 2009), to assess the risk to aquatic ecosystem components, processes and services from the water management scenarios for the specific WRP area. This "critical flow" framework is somewhat different to others that propose the development of flow-ecology relationships for individual rivers or river types (e.g. Warfe et al., 2014) or for overall flow regimes (e.g. Poff et al., 2010) but is consistent with that of Clifton et al. (2007).

METHODS

THE FRAMEWORK

The "critical flow" ecological risk assessment (ERA) framework (FIG. 1) focuses on ecological assets that:

- represent the ecological values of the Water Resource Plan area;
- are critically dependent on aspects of the flow regime;
- and are vulnerable to the types of flow alteration reflected in the water resource plan (WRP).

The ERA framework involves the following steps:

1. Values and Assets Identification: identifying ecological assets in the WRP area that are linked to both the ecological values of the area and to its surface and/or groundwater resources and that are potentially sensitive to changed water allocation and management conditions;
2. Asset Prioritisation: identifying the water requirements of the ecological assets (magnitude, duration, timing, rate of change, quality of flow/groundwater exposure) which provide opportunities for key ecological responses and/or geomorphologic processes that support the viability of the assets. Assets

TABLE 1. Existing Environmental Management Rules (EMR) based on Gen 1 Environmental Assessment and improvements suggested as a result of Gen 2 Environmental Assessment of the Burnett Basin Water Resource Plans 2000 (Gen 1) and 2014 (Gen 2).

Gen 1 EMRs	Links to Outcomes	Outcomes Achieved by Gen 1 WRP and improvements suggested for Gen 2 WRP
Water levels in a given storage to be maintained at Nominal Operating Levels	Maintain riverine and estuarine processes, connectivity, fish movement and maintenance of pool habitats	Most outcomes were achieved but further improvements were suggested for Ned Churchwood Weir, Ben Anderson Barrage and Bucca Weir
Controlled rate of release downstream of Paradise Dam, Ned Churchwood Weir and Bucca Weir	As above, plus water quality	Not achieved since rate of release was too rapid resulting in rapid changes to water levels, resulting in fish kills. Suggested release to reflect natural flows
Maintain low flows objectives	Maintain pool habitats, water quality, fish movements	Some outcomes achieved by further improvements suggested for Paradise Dam and Ned Churchwood, Bucca and Claude Wharton Weirs
Medium and high flow objectives	As above plus riverine and estuarine processes, and connectivity	Improvements suggested to ensure flows are transmitted to the estuaries to ensure sufficient brackish habitats are provided at critical times of the year
Operation of fish transfer devices	Fish movement and connectivity	Outcomes achieved

representing high values (e.g. RAMSAR, threatened or rare and endangered species) are given higher priority over others provided they have identified critical links to flow. This is done through stakeholder workshops. Assets known to be affected by critical components (e.g. high, medium, low flows) are also included in the final list.

3. Asset Flow Requirements: identifying frequency of flow/groundwater conditions that provide appropriate opportunities for key ecological responses and/or geomorphologic processes to maintain (or to restore where appropriate) the long term viability of the priority assets.
4. Risk Assessment: assessing the risk of possible impacts to ecological assets from water allocation and management scenarios, including the nature and extent of the risk;
5. Mitigation Recommendations: making recommendations on potential mitigation strategies to minimise identified risks; and
6. Monitoring and Evaluation: providing recommendations and priorities for monitoring and evaluation, and future research requirements including filling of existing knowledge/data gaps.

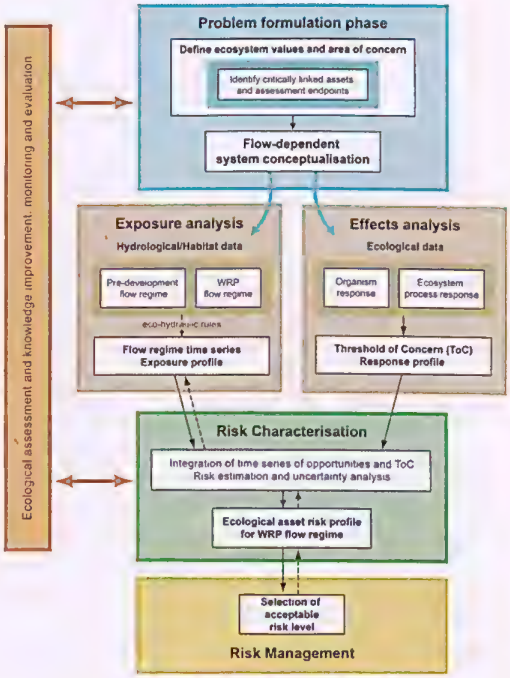
Problem formulation phase
Define ecosystem values and area of concern
Identify critically linked assets and assessment endpoints
Flow-dependent system conceptualisation
Exposure analysis
Hydrological/Habitat data
Pre-development flow regime
WRP flow regime
eco-hydraulic rules
Flow regime time series Exposure profile
Effects analysis
Ecological data
Organism response
Ecosystem process response
Threshold of Concern (ToC) Response profile
Risk Characterisation
Integration of time series of opportunities and ToC
Risk estimation and uncertainty analysis
Ecological asset risk profile for WRP flow regime
Selection of acceptable risk level
Risk Management
Ecological assessment and knowledge improvement, monitoring and evaluation

FIG. 1. Ecological risk assessment (ERA) framework for flow dependent ecosystem components, processes and services (adapted from Clifton et al., 2007).

VALUES AND ASSET IDENTIFICATION

Current scientific processes in environmental assessments recognise the importance of establishing societal values in order to achieve adaptive management through ecologically based and socially acceptable management goals (Poff & Zimmerman, 2010; Poff et al., 2010). The ecological assets are generally representative of the ecological values held by the community. Both the values and associated assets relevant to a WRP area are identified from a comprehensive review of the scientific literature, technical reports, guidelines, action plans, regional ecosystem mapping, government databases, and consultation with relevant local experts and stakeholders. Ecological assets may be a species, a group of species, a biological function, an ecosystem or a place of natural value. They occur in the WRP area of interest, have an aspect(s) of life history or process requirement critically linked to characteristics of the flow regime (e.g. low, medium, high flows), and are sensitive to the nature of flow regime alteration relevant to the area of interest. Each WRP area contains a unique set of ecological assets and related ecological outcomes. Consequently ecological assets selected for each WRP area differ across the state. Additionally, the flow requirements of a specific ecological asset may also vary between WRP areas due to the different eco-hydrologic settings that characterise each Basin. The risk to ecological assets from water resource development represented by the draft WRP is the focus of the environmental assessment process.

Information on the ecosystem asset's location and distribution, status under State and Commonwealth legislation, and critical links to surface or groundwater, is collated. Species of conservation significance, as declared under the *Nature Conservation Act 1992* and the *Environmental Protection and Biodiversity Conservation Act 1999* (Commonwealth) are explicitly considered. Additional local information is sourced via an expert workshop that brings together scientific experts from academia, government agencies, and industry to assist in the identification of potential ecological assets in the Plan area, which are linked to both the ecological values of the area and to the impacts of water allocation and management scenarios associated with the specific WRP. As an example, the combined data sources and information collated from the workshop for the Wet Tropics WRP area resulted in a list of over 6400 ecosystem components that were spatially relevant and water dependent (e.g. many species of aquatic plants, fish, crustaceans, amphibians and reptiles). The ecosystem components identified are then subjected to two prioritisation processes to determine their status as potential ecological assets for the purpose of the environmental assessment: 1. critical links to the surface water flow regime or groundwater regime; and 2. potentially sensitive to water allocation and management (FIG. 2).

A critical link to the flow regime is defined as having an aspect of an ecological asset's life history or process requirement critically linked to characteristics of the flow regime, i.e. one or more of an ecological asset's responses necessary for long-term viability is dependent on the conditions provided by flow. In most cases, these conditions are provided through the direct provision of flow. However, in some cases, the absence of flow provides the required conditions for the asset (e.g. an ephemeral wetland undergoes natural cycles of wetting and drying). For the life cycles of many species this critical link can be broken down into two phases: 1. maintenance and persistence of the adults, and 2. regeneration and recruitment via reproduction (Overton et al., 2009). For each stage a review of the best current scientific knowledge is used to describe the nature of the flow dependency by defining the flow related conditions needed to trigger the ecological response. An asset's vulnerability to water resource development (WRD) is defined as a potential interaction between the ecological assets and the altered flow regime. Typically this is determined spatially, considering interactions between the asset's distribution and sections of stream network which have an altered flow regime. To ensure a robust prioritisation of potential ecological assets, all critically linked surface water ecological assets with distributions corresponding to the Plan area are generally usually considered potentially vulnerable.

ASSET PRIORITISATION

From the pool of ecological assets identified as having a critical link to the flow regime a subset is prioritised for more detailed risk assessment. This is based on the robustness of the information about their flow-ecology requirements (expressed in terms of facets of the flow regime) and supporting habitat data (e.g. waterhole bathymetry, cross sectional areas, water temperature). This information is required to formulate a set of quantitative flow requirements (termed eco-hydraulic rules) to be applied in an ecological risk modelling process. Furthermore, only

assets that have flow-ecology requirements that are potentially vulnerable to the types of flow regime changes possible in the WRP area are prioritised based on the entitlements (e.g. existing licences, commitments to users) and types of infrastructure in the Plan area. The types of flow regime modification possible within the WRP area are identified by an iterative process: first, considering the WRP's allocation entitlements in light of the links to flow of the suite of assets with sufficient information to model, and secondly, considering specific aspects of flow linked directly to the ecological outcomes of the WRP (FIG. 2). Many of the prioritised assets share common flow requirements and vulnerabilities. On this basis, these are grouped into guilds of assets. An example of a guild type is fish with similar flow related recruitment strategy (Arthington, 2012). Within guilds, some assets are better understood than others with respect to their flow requirements, and thus have greater utility in the modelling of risk from alternative flow management options.

DETERMINING SPECIFIC FLOW REQUIREMENTS

The environmental assessment uses an eco-hydraulic modelling approach to assess the risk to ecological assets from water resource development. Therefore, only those ecological assets with sufficiently detailed knowledge on their flow-ecology requirements (expressed in terms of facets of the flow regime) and supporting habitat data (in terms of waterhole bathymetry, stream cross sectional areas, etc.), are candidates for detailed quantitative risk analysis. A detailed review of the scientific literature and consultation with relevant technical experts is conducted for each of the candidate ecological assets. This information is distilled into discrete aspects of the flow regime with respect to location, timing, magnitude, duration, frequency, habitat features and associated water quality attributes where relevant. This expression of flow regime facets that support critical life history or process

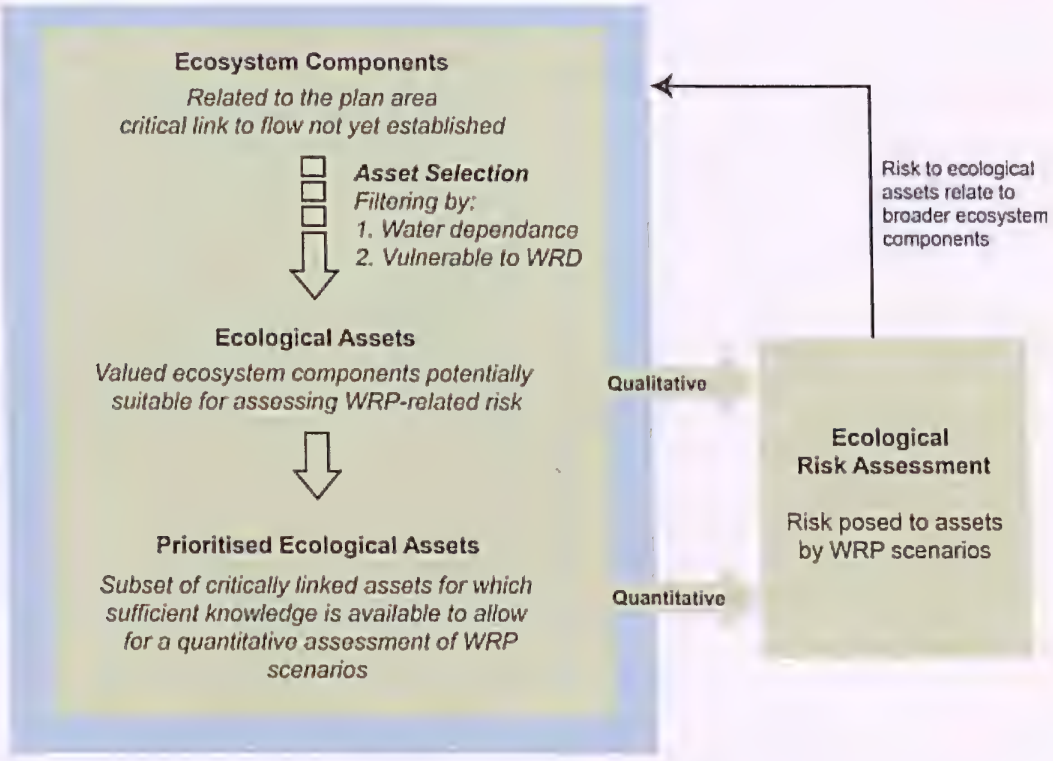
Ecosystem Components
Related to the plan area
critical link to flow not yet established
Asset Selection
Filtering by:
1. Water dependance
2. Vulnerable to WRD
Ecological Assets
Valued ecosystem components potentially suitable for assessing WRP-related risk
Prioritised Ecological Assets
Subset of critically linked assets for which sufficient knowledge is available to allow for a quantitative assessment of WRP scenarios
Qualitative
Quantitative
Ecological Risk Assessment
Risk posed to assets by WRP scenarios
Risk to ecological assets relate to broader ecosystem components

FIG. 2. Overview of the use of ecological asset selection process and risk assessment.

events, forms the basis for determining how the managed flow regime alters the provision of these opportunities over time, and hence represents a risk to the asset's long term viability.

DEFINING THE ASSESSMENT ENDPOINTS

Assessment endpoints are used to explicitly define the environmental values of concern and provide the focus for analysis and characterisation in ERAs (USEPA, 1992; van der Oost et al., 2003; Suter II, 2009). Endpoints can include species and life stages, multiple levels of organisation and numerous structural and functional attributes. Assessment endpoints are those characteristics/attributes of the valued ecological entity which are believed to be at risk (i.e. vulnerable). In this context the assessment endpoints are the flow-dependent ecological components, processes, and services of the specific WRP area. The assessment endpoint has two components: 1. the entity - which is the valued aspect of the ecosystem (i.e. ecological asset such as a fish, plant, turtle, waterhole, etc.); and 2. the attribute of the entity - such as abundance, fecundity, recruitment, extirpation, persistence, etc. Assessment endpoints are generally estimated using measurement endpoints. Measurement endpoints (also known as measures of effect) are expressions of observed or measured responses to the stressor, a measurable characteristic that is related to the assessment endpoint. Examples include measures of fecundity, recruitment and survival. Measurement endpoints are derived via laboratory or field based observational studies that are used to estimate the effects on an assessment endpoint or exposure to a stressor. Measurement endpoints are typically the focus of the risk assessment and link the assessment endpoints to the risk assessment. When an assessment endpoint can be directly measured, the measurement and assessment endpoints are the same. In most cases, however, the assessment endpoint cannot be directly measured, so a measurement endpoint (or a suite of measurement endpoints) is selected that can be related, either qualitatively or quantitatively, to the assessment endpoint (USEPA, 1992). For most of the species based ecological assets considered in the assessment, the measurement endpoints relate to spawning and recruitment opportunities linked to aspects of the flow regime. Measurement endpoints for ecological process- and service-related ecological assets vary; however typically they relate to the provision of critical habitat, or the conditions which support ecosystem structure and/or function.

ESTABLISHING CRITICAL FLOW REQUIREMENTS (ECO-HYDRAULIC RULES)

The exposure analysis phase of the ERA (FIG. 1) uses information on the flow requirements of the prioritised ecological assets to develop a time series of opportunities for each water resource development scenario as it relates to a specific ecological response defined as the measurement endpoint. The requirements of ecological assets in terms of aspects of the flow regime (e.g. magnitude, duration, timing, rate of change) are defined and expressed as eco-hydraulic rules. For each ecological asset, best current scientific understanding is used to describe the nature of the flow dependency by defining the flow related conditions needed to trigger an ecological response. This understanding is used to formulate eco-hydraulic rules which define an opportunity for the ecological response in terms of facets of the flow regime. For example:

> Spawning trigger flow = X magnitude for Y period between T_1–T_2 time of the year

These eco-hydraulic rules are then applied to a daily flow time series representing a water resource development scenario to generate a time series of opportunities for the ecological response to occur. This likelihood or exposure data represents the probability of an ecological asset/indicator experiencing the critical flow/habitat conditions required, when and where they are needed over the assessment period.

DEFINING THRESHOLDS OF CONCERN (TOCS)

The effects analysis phase of the ERA (FIG. 1) uses information on the consequence of altering the provision of the critically-linked response to the long term viability of the ecological asset. Defining what constitutes sufficient opportunities for an ecological response in order to maintain the viability of an ecological asset remains a global knowledge gap in the scientific literature for a great many flow dependent species and processes (Arthington et al., 2006; Poff et al., 2010; Arthington, 2012; Poff & Matthews, 2013; Webb et al., 2015). The application of coarse hydrological metrics such as percentage of pre-development flow regime oversimplifies the temporal hydrological sequence experienced by the ecosystem and have long since been superseded by more quantitative hydro-ecological relationships derived empirically. These statistics ignore the obvious relevance of timing, spell durations, and do not adequately represent the complex interactions

between hydrology and ecological responses to change in hydrology (Arthington et al., 2006; Poff et al., 2010). In this ERA flow context, consequence or effects data is the characterisation of an adverse ecological effect or response. Consequence is the impact on the valued attributes of an ecological asset/ indicator of not providing the conditions it critically requires. Ideally, defining sufficient opportunities is informed by response functions derived from controlled observational or manipulation-based studies of flow-ecology interactions. In the absence of widely applicable general response functions, best available science can be used to derive step functions or thresholds which represent critical change or failure points along a response gradient. This process has been proposed in the ELOHA framework (Poff et al., 2010). In this WRP application, Thresholds of Concern (ToC) (*sensu* Rogers & Biggs, 1999) are defined to represent the frequency of opportunities required to protect asset viability. ToCs represent failure points for the ecological asset and as such can be considered minimum water requirements. Therefore, the probability of achieving a desired ecological outcome is directly related to meeting a ToC over time. Where possible, ToCs are based on the biology or process knowledge of the asset. In most cases, ToCs represent the known length of time a species-based ecological asset will survive without experiencing a flow-based opportunity (for responses related to maintenance and persistence dependencies) or the reproductive life time of the asset (for responses related to regeneration and recruitment dependencies). For those ecological assets without a clear life history basis for setting a ToC, thresholds can be related to the frequency of opportunity provision modelled to occur under the pre-development flow regime. Because even natural flow regimes are not without risk to ecological assets, the risk from management scenarios will be considered relative to the risk from the conditions of the pre-development flow regime.

The process outlined above requires both a sound conceptual understanding of the flow dependent ecological assets and detailed biological and/or process knowledge relating to their critical flow dependencies. The synthesis of this knowledge is presented for each ecological asset, or group of assets (guild), and forms the basis for the ecological model development and setting of ToCs, which will subsequently be used for the quantification of risk to those assets from various water resource development scenarios.

ASSESSING THE RELATIVE RISK TO ECOLOGICAL ASSETS FROM WATER RESOURCE DEVELOPMENT SCENARIOS

Different surface water development (SWD) scenarios can be assessed across a WRP area. The scenarios generally include: pre-development, which assumes no water resource development in the Plan area; current entitlement, which reflects the current use of existing entitlements; and full entitlement, which reflects the full use of existing entitlements. Simulated daily flow time series (as ML/day) are modelled for the SWD scenarios at a series of environmental assessment nodes, representing stream flow gauging stations in the WRP area, using the water resources management model, the Integrated Quantity Quality Model (IQQM). The IQQM is a hydrological system simulation model which operates on a daily time step. A 100+ year simulation period can be modelled for periods from the late 1800s to current. The eco-hydraulic rules for each ecological asset are applied to the modelled daily flow time series (EcoModeller V 2.0.6, eWater CRC) to generate a time series of flow-related opportunities for the ecological response over the simulation period. This is undertaken for each of the IQQM scenarios at each relevant node. Opportunities in these time series are represented by days in which all daily flow requirements defined by the eco-hydraulic rules were met. At the node scale the risk to ecological assets are expressed as the percentage of years in the simulation period which are in either a low or high risk category as defined by the ToC for the asset being assessed (TABLE 1). Low risk events are periods in the time series of opportunities where the ToC is met by the flow scenario; whereas high risk events are represented by periods when the ToC is not met (otherwise referred to as a node failure). Where appropriate, for assets with multiple ToCs, node failures are refined into moderate or high risk events depending on which of the ToCs are not met. For ecological assets where no ToC can be derived, because insufficient knowledge is available to do so, hazard rather than risk posed by the development scenarios is identified and discussed in relation to the proportional change in opportunities from the pre-development scenario. In this context "hazard" is something that can cause harm and "risk" is the chance, high or low, that any hazard will actually cause harm.

The process outlined above requires both a sound conceptual understanding of the flow dependent ecological assets and detailed biological and/or

process knowledge relating to their critical flow dependencies. Further details on the approach used for each asset are given in the next section of this paper.

RESULTS AND DISCUSSION

ASSET SELECTION AND PRIORITISATION

Environmental assessments for several Gen 2 Water Resource Plans have been completed (for example, see DSITIA, 2013a; 2013b). For the Wet Tropics WRP, 154 surface water dependent ecological assets were identified as having a direct dependency on aspects of the flow regime. They included plants, fish, reptiles, amphibians, in-stream habitats and estuarine fisheries. Two categories of groundwater dependent ecosystem components were considered: (i) terrestrial vegetation, and (ii) non- riverine wetlands. Seventy Regional Ecosystem types (including 186 sub-communities) and 55 wetlands were identified as potentially dependent on groundwater (DSITIA, 2013a).

TABLE 2 provides an example of the prioritised surface water assets in the Warrego-Paroo-Bulloo-Nebine WRP area of the northern Murray-Darling Basin. Of the 94 candidate assets, these were ones for which sufficient knowledge of their flow requirements was available to enable detailed analysis of the impact of water resource development on their persistence (DERM, 2011). The prioritised assets rely on a range of hydrologic conditions which were identified as having the potential to be altered by the water resource plan including: refuge waterhole persistence, in-channel flows, bank full discharge for sediment mobilisation, inundation of floodplains and wetlands, and longitudinal and lateral connectivity. Among them, the prioritised assets represented or supported a range of ecological values, encompassed all of the water resource plan ecological outcomes, and as a suite, address the environmental asset and ecosystem function criteria set out in the Murray-Darling Basin Plan (Schedules 8 & 9 in MDBA, 2011).

Several species of waterbirds (e.g. *Stictonetta naevosa, Tringa stagnatilis* and *Ardea* spp.) were considered for prioritisation because they rely on seasonal flooding of wetlands for breeding or overwintering, and significant proportions of their total populations are known to use wetlands within the plan area at some time (Marchant & Higgins, 1990; Watkins, 1993; Arthur, 2011). However, because individuals are highly mobile, the scale of local populations is much larger than individual river basins, spanning large areas of the continent or even the globe, with broad-scale rainfall patterns driving waterbird abundance in eastern Australia (Padgham, 2011). This meant that hydrological requirements for the viability of these populations could not be established for the Plan area in isolation (Roshier et al., 2001a, b; Kingsford et al., 2010). Waterbirds are therefore, captured in a general sense as one of the ecological values associated with the floodplain wetlands asset.

For the Burnett Basin, the selected ecological assets included the Australian lungfish (*Neoceratodus forsteri*), White-throated snapping turtle (*Elseya albagula*), estuarine brackish habitats and waterholes. Since estuaries are a specific habitat type that represents a continuum of water salinities, and species within this habitat have specific water requirements, the asset was assessed as several estuarine components including barramundi (*Lates calcarifer*), sea mullet (*Mugil cephalus*), banana prawns (*Fenneropenaeus merguiensis*) and river mangrove (*Aegiceras corniculatum*) (DSITIA, 2013d).

ASSET FLOW REQUIREMENTS

From the sub-set of ecological assets, data on their life history or process requirements were distilled into discrete aspects of the flow regime with respect to location, timing, magnitude, duration frequency, habitat features and associated water quality attributes where relevant. This allowed the risk to the asset's long term viability to be assessed. For the Warrego-Paroo-Bulloo-Nebine WRP area surface water dependent assets were categorised into four hydrological classes based on their critical flow requirements (TABLE 3). Each hydrological class represented a particular aspect of the flow regime. By categorising assets into these classes, the risks to assets could be understood in relation to specific changes to the flow regime that occur as a result of water resource development. As an example, the assessment endpoints for each of these assets and their link to hydrology (hydrologic class) for the Warrego River are summarised in TABLE 4. The exposure analysis of the risk assessment used information on the flow requirements to develop a time series of opportunities for each water resource development scenario as it related to a specific ecological response defined as the measurement endpoint. The flow requirements of ecological assets in terms of aspects of the flow regime (e.g. magnitude, duration, timing, rate of change) were defined and expressed as eco-hydraulic rules. Eco-hydraulic rules were then applied to a daily flow time

TABLE 2. Surface water ecological assets used in the environmental assessment, their link to hydrology, assessment endpoints, and their distribution in the Warrego-Paroo-Bulloo-Nebine WRP area of the northern Murray Darling Basin. Ticks indicate assets used in the ecological risk assessment, while circles indicate assets present in a catchment but unassessed because there was no difference in the relevant aspect of hydrology between flow scenarios.

		Link to hydrology				Catchment			
Ecological asset	**Assessment endpoint**	No-flow	Low flows	Medium flows	High flows	Warrego	Paroo	Bulloo	Nebine
Ecosystem components									
Flow spawning fish	Population viability of Yellowbelly (Macquaria ambigua)	✓	✓	✓	✓	✓	✓	✓	✓
Migratory fish species	Maintenance of movement opportunities for migratory fish species	✓	✓	✓		✓	○	○	✓
Eastern snake-necked turtle (Chelodina longicollis)	Population viability of Eastern snake-necked turtle (Chelodina longicollis)	✓			✓	✓	○	○	✓
Absence of exotic fish species	Minimised abundance and distribution of European carp (Cyprinus carpio)			✓	✓	✓	○	○	✓
Floodplain vegetation	Viability of floodplain vegetation communities				✓	✓	○	○	✓
Floodplain wetlands	Maintenance of wetting regime to support floodplain wetlands				✓	✓	○	○	✓
Unique genetic diversity of aquatic biota within the Bulloo basin	Absence of translocated genotypes of Yellowbelly in the Bulloo							✓	
Ecosystem processes									
Waterholes as refugia	Spells of no-flow isolation Distance between waterholes	✓	✓			✓	✓	✓	✓
Fluvial geomorphology and river forming processes	Events at or above bankfull flows			✓	✓	✓	○	○	○

series representing a water resource development scenario to generate a time series of opportunities for the ecological response. This likelihood or exposure data represented the probability of an ecological asset/indicator experiencing the critical conditions required when and where they are needed over the assessment period. The effects analysis of the ERA used information on the consequence of altering the provision of the critically-linked response to the long term viability of the ecological asset. Because even natural flow regimes are not without risk to ecological assets, the risk from management scenarios was considered relative to the risk from the pre-development flow regime.

ECO-HYDRAULIC MODELLING AND RISK ASSESSMENT

Daily flow time series (as ML/day) were modelled for the pre-development and development scenarios at a series of nodes in the water resources management model called the Integrated Quantity and Quality Model (IQQM). The IQQM model is a hydrological

TABLE 3. Hydrologic classes of surface water dependent assets based on their critical flow requirements in the Warrego-Paroo-Bulloo-Nebine WRP area.

Hydrologic Class	Summary description of surface water dependant assets	Examples of asset types
No Flow	No-flow assets have a critical flow requirement that is linked to periods of no river flow.	Water-holes, small fish, Eastern snake-necked turtles.
Low Flows	Low flow assets have critical flow requirements that are linked to low flow events, which are typically associated with flows persisting outside of flood events and events associated with high, seasonal rainfall. For example, these links may be associated with baseflow contributions from groundwater or contributions from small rainfall events in the dry season.	Migratory fish, water-holes.
Medium Flows	Medium flow assets have critical flow requirements that are linked to medium flow conditions. These links are typically associated with intermediate flow conditions that occur between low and high flows. For example, these links may be associated with flow periods following flood events as flow subsides, or with rainfall events of sufficient size to increase flow volumes but not large enough to produce flooding.	Migratory fish, in-stream habitats.
High Flows	High flow assets have critical flow requirements that are linked to high flow conditions that are typically associated with high, seasonal rainfall during wet periods. For example, these links may be associated with flood plain inundation or spawning/migration cues.	Migratory fish, wetlands, floodplain vegetation.

system simulation model that operates on a daily time step. For the Warrego, Paroo, Bulloo and Nebine river basins, a 122 year simulation period was modelled for the period 1889–2011 inclusive. For each ecological asset, eco-hydraulic rules are defined that express their critical flow requirements. These rules are applied to the modelled daily flow, river height, salinity and temperature time series to generate a time series of flow-related opportunities for the ecological responses, over the simulation period (EcoModeller V2.0.6, eWater CRC). Opportunities are represented by days for which all daily flow, height, and temperature requirements are met. Using the approach outlined above, risks to assets are modelled under the two water resource development scenarios: 1. pre-development–assumes no water resource development in each catchment and 2. full entitlement–reflects the full use of existing entitlements with current Resource Operating Rules. The first scenario represents low risk for ecological assets and the second is often for high risk, depending upon how water entitlements are allocated and managed. It is now recommended that an intermediate scenario (e.g. existing level of entitlement) be considered so that the assessment can make recommendations about the options to avoid the most serious likely risks to ecosystems. Risk to ecological assets is modelled at assessment nodes reflecting their present distribution. Because even unmodified flow regimes are not without risk to assets, the risk to ecological assets is expressed in terms of the frequency of ToC exceedance over the simulation period, contrasting the development scenarios with the pre-development scenario. For the Warrego catchment detailed analyses were conducted on eight ecological assets and the results are summarised in TABLE 4. Conceptual models (FIG. 3) and flow relationships (FIG. 4) underpinned all assessments. Overall, the environmental risk assessment identified low risk to surface water ecological assets from water resource management activities (such as water extraction) in the Plan area (DSITIA, 2013c). A broad threat prioritisation undertaken for the region as part of the Queensland Government's Stream and Estuary Assessment Program (SEAP) also indicated that

TABLE 4. Summary of risks to ecological assets (under the full water entitlement scenario) of the Warrego catchment, their link to hydrology and modelled risk in comparison to the pre-development scenario.

Ecological asset	Assessment endpoint	Link to hydrology	Risk in comparison to pre-development*							
			423204A Augathella	423201A Charleville	423203A Wyandra	423206A Wallen	423202C Cunnamulla	423004 Barringun	423005 Turra	Whole catchment
Ecosystem components										
Flow spawning fish	Abundance of yellowbelly	no-flow, medium flow, high flow	low	low	low	low	low	low	low	low
Migratory fish species	Frequency of longitudinal connectivity opportunities	no-flow, medium flow	low	low	low	low	low	low	low	n/a
Eastern snake-necked turtle (Chelodina longicollis)	Frequency of high stress events	no-flow, high flow	low	low	low	low	low	low	low	low
Absence of exotic fish species	Frequency of strong recruitment opportunities for European carp	medium flow, high flow	0%	n/a	–1.6%	n/a	0%	–2.5%	0%	n/a
Floodplain vegetation and wetlands	Length of spells between inundation events	high flow	0%	n/a	0%	0%	0%	+4%**	0%	n/a
Ecosystem processes										
Waterholes as refugia	Spells of no-flow isolation (maximum no-flow spell duration)	no-flow, low flow	0%	0%	+2%	+2%	+25%	–6%	0%	n/a
	Change in the distance between permanent waterholes due to licenced waterhole pumping	no-flow, low flow	n/a	n/a	n/a	n/a	n/a	n/a	n/a	+2%
Fluvial geomorphology and river forming processes	Duration of events at or above bankfull flows	medium flow, high flow	0%	0%	0%	–0.6%	–3%	–8%	–5%	n/a

* risk expressed as exceedance of ToC or proportional deviation from pre-development where no ToC could be determined; n/a = not assessed

** At the moderate flood threshold, spells between flood inundations of greater than 12 months increased from 37% under predevelopment to 41% under full entitlement. There was no increase in spell length at other flood threshold levels.

the risk to aquatic ecological condition from water resource management was low (Negus et al., 2012). In some instances, however, assets have increased risk profiles because the provision of hydrologic conditions that support them has been impacted under the full entitlement flow scenario. For example, reduction in medium flows would reduce available habitat or reproductive opportunities. Also, the risk to some assets could not be comprehensively assessed because insufficient information about the consequence of changed conditions was available. Potential groundwater dependent ecosystems (GDEs) were identified across the Plan area (DSITIA, 2013c), but risk to these from the current Plan could not be assessed because there was insufficient information available on both their dependency on groundwater hydrological attributes and how current management has modified natural groundwater hydrology. Improved data and knowledge on both aspects are required before assessments of risk to GDEs can be undertaken in future. This has been recommended as future monitoring and research requirement as part of the implementation plan.

MONITORING, EVALUATION AND KNOWLEDGE GAPS

The risk assessment identified the ecological assets that have critical links to flows and as such clearly identified what monitoring needs to be carried out to assess the WRP in terms of meeting its intended ecological outcomes and further information for future improvement under the Adaptive Management Framework. It also identified knowledge gaps and uncertainties that need to be addressed. For the Queensland Murray-Darling catchments, a diverse array of waterbirds is known to utilise inundated floodplain wetlands in the Plan area. Whilst they are frequently cited as an important ecological value, the magnitude of flows required to inundate wetland habitats, the period of inundation, the interaction between flow and habitat quality (e.g. vegetation for nesting, food availability), the scale of bird populations and the spatial patterns of habitat use cannot be adequately determined based on the current understanding. Therefore, eco-hydraulic rules linking aspects of the flow regime to waterbird population viability could not be confidently developed. Further information about the critical aspects of the

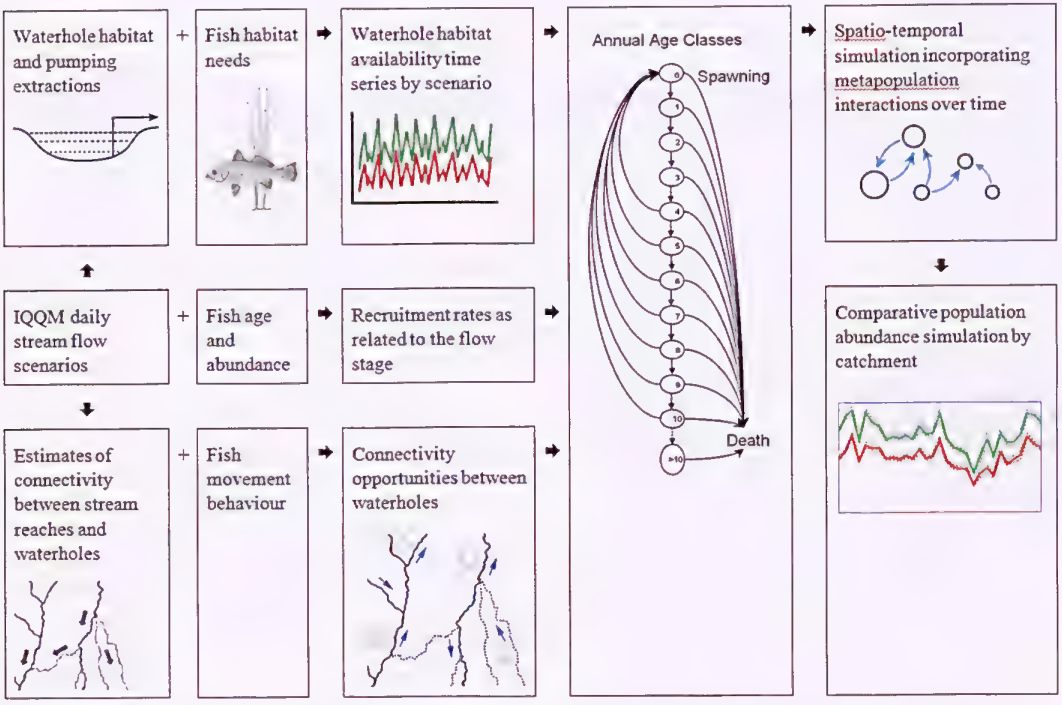
Waterhole habitat and pumping extractions
+
Fish habitat needs
Waterhole habitat availability time series by scenario
IQQM daily stream flow scenarios
+
Fish age and abundance
Recruitment rates as related to the flow stage
Estimates of connectivity between stream reaches and waterholes
+
Fish movement behaviour
Connectivity opportunities between waterholes
Annual Age Classes
Spawning
Death
Spatio-temporal simulation incorporating metapopulation interactions over time
Comparative population abundance simulation by catchment

FIG. 3. Conceptual model of the Yellowbelly meta-population model for the Warrego, Paroo, Bulloo and Nebine rivers.

flow regime required by potential ecological assets would enable a more robust quantitative assessment utilising a wider variety of ecosystem components. Monitoring under the Queensland Government's Environmental Flows Assessment Program (EFAP) and targeted research such as those under the Dryland Refugia, SEQ Ecological Limits of Hydrological Alteration (ELOHA) and Tropical Rivers and Coastal Knowledge (TRaCK) are generating many useful flow-ecology relationships (e.g. Warfe et al., 2014) and documenting the effects of flow regimes that could be used in future reviews.

CONCLUSIONS

Water allocation in Queensland is carried out through a statutory water resource planning process administered under the *Water Act 2000*. A Water Resource Plan provides the framework for this water allocation for sustainable and secure consumptive and non-consumptive uses as well as providing water necessary to sustain the aquatic environment, including both surface water and groundwater dependent ecosystems. This paper describes Queensland's current approach to assessing environmental water allocations based on risk assessment and the probable ecological impacts of different water resource management scenarios. This current in-house approach is different to that previously used in the earlier Water Resource Plans (WRP) which relied on a Technical Advisory Panel (TAP) that consisted of group of mainly external scientists who were selected based on their area of expertise and scientific knowledge of the WRP area. Given that very little project specific scientific data were available and that new ecological data could not be collected at that time, these earlier assessments were based on the "Benchmarking Methodology" that relied heavily on the knowledge and opinions of the TAP members and were, in some cases, somewhat subjective (Brizga et al., 2002). The current assessments benefit from a lot more and recent project specific scientific data that allowed a more objective assessment based on the Australian Standards risk assessment approach (e.g. AS/NZS, 2009) that is accompanied by a statement on the level of confidence of each assessment. As in the case of the Benchmarking Methodology, key knowledge gaps are also identified during the process so that targeted monitoring and/or research can be carried for further refinement or future assessments. For this risk assessment, environmental values and their associated ecological assets to be protected are identified and prioritised. The prioritisation of the assets is based on their critical links to flow and how these links may be affected by the different water allocation and management scenarios. Examples from the different water plan areas are provided to illustrate the results. The outcome is that there is more confidence in the environmental assessments on which environmental water allocations are made in the Generation 2 Water Resource Plans. Given that the water planning process is based on an adaptive management strategy, continual improvement and confidence in all aspects of the process is expected from on-going monitoring, research and advances in modelling risk.

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I would like to thank Gary Burgess (former Manager, Water Planning) of the Queensland Department of Natural Resources and Mines (DRNM) for insisting that further objectivity be incorporated into the scientific assessments of Water Resource Plans rather than relying on the Technical Advisory

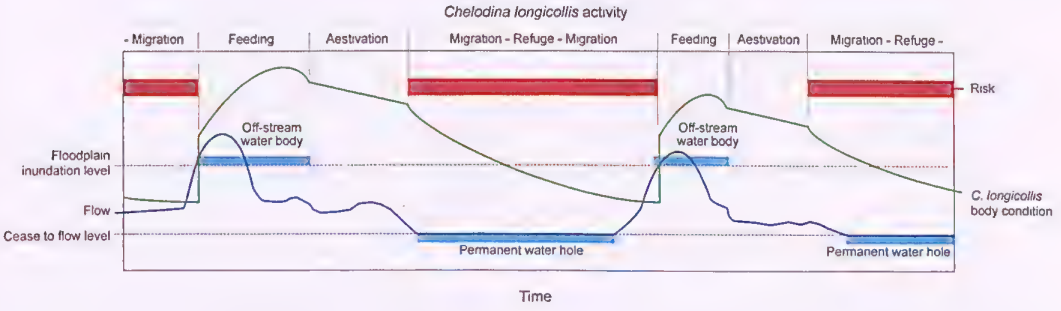

FIG. 4. Conceptual relationships between flow magnitude, habitat availability, and risk to the eastern snake-necked turtle (*C. longicollis*) over time. The red horizontal bars indicate the periods of risk that were modelled. Those periods include refuge in permanent water holes and well as migration to and from those water-holes.

Panel. Lyall Hinrichsen (former Executive Director, Water Planning) and his staff in DNRM provided valuable input and guidance into the assessments and were responsible for the successful delivery and implementation of the many Water Resource Plans in Queensland. Glenn McGregor from the Water Planning and Ecology Group (WPE), Department of Science, Information Technology and Innovation (DSITI) coordinated the delivery of the science assessments with invaluable input from ecology and hydrology staff within DSITI as well as from central office and regional staff of DNRM.

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AUTHOR PROFILE

Dr Satish Choy is an aquatic ecologist and currently an Adjunct Senior Research Fellow at the Australian Rivers Institute, Griffith University in Brisbane. He was formerly Science Leader in the Queensland Department of Science, Information Technology and Innovation (DSITI) where he led the environmental water allocation assessments for all of Queensland's Water Resource Plans and provided the science-policy linkage for water related issues.

MAPPING HISTORICAL LIVESTOCK GRAZING PRESSURE IN QUEENSLAND

IRVINE, S.A.

The comparison of historical livestock grazing maps can provide insights into the long term environment impacts of grazing upon different landscapes. The Queensland State Statistics (QSS) (1860-1949) describes at a district level, the numbers of cattle, horses and sheep providing a record of introduction and development of the sheep and cattle industry throughout Queensland. The livestock record from the QSS has been spatially defined to provide a history of pastoral land use in Queensland. To account for livestock change at local statistical areas, it was necessary to determine changes in statistical boundaries over time and to spatially distribute stock according to the statistical area that was described in the QSS. This was achieved by applying a stock distribution model (SDM) in order to calculate an estimated yearly stocking rate within each QSS district. In the absence of other data, the methodology presented displays a more accurate representation of stock movement and subsequent grazing during the Queensland's development period. More importantly the data collected and standardised across the mapping units allows for the AussieGRASS (Australian Grassland and Rangeland Assessment by Spatial Simulation) model to extend its grazing modelling capacity to calendar years past 1950 for all areas of Queensland.

Grazing Land Systems, Science Delivery, Queensland Department of Science, Information Technology and Innovation, Ecosciences Precinct, 41 Boggo Road, Dutton Park 4102, Australia

INTRODUCTION

This paper describes a method to disaggregate historical stocking rate information to provide a detailed grazing history for the whole of Queensland from 1860 to 1949. The historical effects of grazing in terms of industry sustainability and management are of great interest to the grazing industry (McKeon *et al.* 2004), for example the assessment of current seasonal conditions relative to the past for all grazing enterprises (Whybrow 2000). Information about past grazing is also a key to natural resource conservation and management contributing to improved assessment of:

1. Impacts on soil and ecosystems processes;
2. Historical exposure of ecosystems to grazing; and
3. Grazing productivity

(Lunt *et al.* 2007).

However, information about grazing history is frequently inadequate. According to Lunt *et al.* (2007) much of the Australian grazing research does not adequately distinguish between the impacts of past and current grazing and that grazing history itself is poorly defined and historically variable. Previous representations of stock numbers in Queensland prior to 1950 have been patchy or only at coarse scales. Stone (2004) reported long-term stocking on a property basis for a few individual properties whilst Daly (1983) reported the same on national and state basis. In both instances herd records, slaughter rates and knowledge of the vegetation were readily available. The AussieGRASS model (Carter *et al.* 2000) employs a similar concept for grazing distribution for calendar years from 1952 but has the benefit of more accurate vegetation assessment and herd statistics.

Lewis *et al.* (2007) used the QSS stock statistics for the Burdekin catchment and found correlations between elevated element concentrations in the Great Barrier Reef to the time when grazing became the main land use. However, Lewis *et al.* (2007) used point source information only and did not take in account stock distribution within the statistical area. Also, a number of records that were based outside the Burdekin Catchment were also incorporated into this study. Additionally, high stock records in the highly suitable native pastures to the south and west of the catchment may have biased the calculation of stock numbers.

Queensland has a long history of stock statistics, with the recording of stock numbers commencing immediately after the Colony of Queensland was proclaimed in 1859. The Statistics of the Colony of Queensland (from 1860 to 1900) became the Statistics of the State of Queensland (1901 to 1974). These statistics are referred to here as the Queensland State

Statistics (QSS) and contain a wide of range of data including yearly return statistics of livestock (horse, cattle, sheep and pig numbers). The QSS continued to 1974, subsequently succeeded by the statistics produced by the Australian Bureau of Statistics. The spatial representation of stock in this study used the QSS records from 1860 to 1949. Prior to 1860, the New South Wales colonial government collected stock statistics, however these records have not been sourced in this study. Pastoral industries have played an important role in the post-European settlement history of Queensland. A general history of the pastoral settlement, development and subsequent changes to native pastures and vegetation in Queensland is provided by Craig (1925), Gramshaw and Lloyd (1993) and Lloyd and Burrows (1987). Pastoral occupation of Queensland commenced in 1840 with squatters moving north from the New England pastoral district proclaimed in 1839 (Queensland State Archives, 2013). The Moreton Bay Penal Settlement founded in 1824 was closed to any settlement until 1839 and squatters were wary not to encroach on the boundaries declared at 50 mile (80.47 km) limit (Craig, 1925). However, outside of these limits squatter settlement progressed.

The dominant and most profitable industry at the time was wool production. Due to the unrestricted availability of land at the time, the procurement of untenured land was common within the wool industry. Free settlement commenced in 1842 (FIG. 1) and continued with the creation of two additional pastoral districts Maranoa and Wide Bay in 1848. Three more pastoral districts were created in 1854, being Burnett (previously part of Wide Bay), Leichardt and Port Curtis. The creation of Burnett was the result of the declaration that made Wide Bay a settled district. In 1859, the Kennedy and Mitchell districts were declared, but implementation was delayed until end of the 1860 due to 'legislative concerns of the new colony' (Kingston 1965).

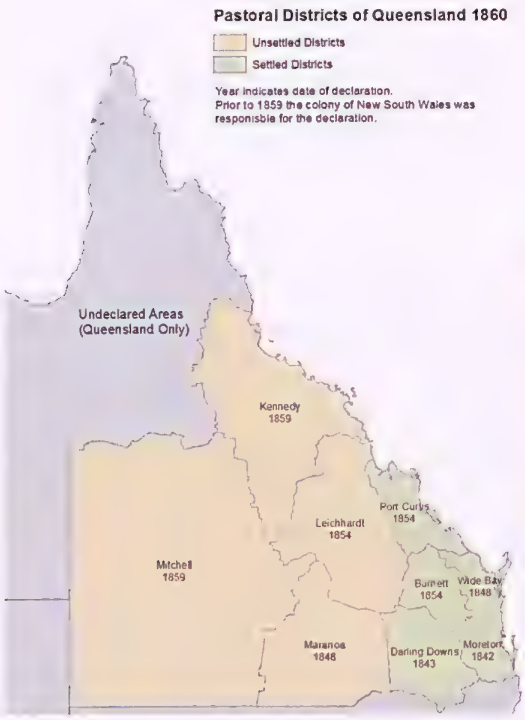

FIG. 1. The approximate locations of the Pastoral Districts of Queensland as at 1860 showing a combination of settled and unsettled districts.

FIG. 2. Map of Queensland, showing the administrative boundaries used for 1860 and settlement pattern after 1862 (adapted from Holmes, 1966).

After 1860 there was continuous expansion for the pastoral industry as settlers continued to move throughout the Colony of Queensland (FIG. 2). The Kennedy and Mitchell pastoral districts were open for settlement (Kingston 1965) (FIG. 2) and by 1868, sheep distribution had expanded throughout the Kennedy and Bourke districts. The sheep expansion into the north and coastal areas proved to be largely unsuitable for wool production (Hall *et al.* 1998). Drought and global financial conditions saw a reversal of growth; and in extreme cases abandonment of homesteads (Holmes 1966). It was not until the mid-1880s, when a second wave of expansion occurred that pastoral occupation in northern and western Queensland was completed. Access to groundwater, changes to property ownership and access to new capital from the southern colonies, appear to have been the main drivers in the development of the cattle industry after *c*1890 (Lloyd and Burrows 1987). The cattle industry became dominant in northern Queensland due to the advantages of lower capital costs (de Satge 1901) and increasing local demand for beef and leather. Drought during 1868-1878 and 1901-1904 kept stock numbers low.

The full economic potential of the cattle industry was only established in times of market security and/or access, which was achieved during 1914-1920 and 1939-1945 when export demand and market quotas combined to force beef prices higher (Daly 1980). However, profitability of beef enterprises was not as high for wool production, leading to consolidation of the wool industry in the central and southern interior of Queensland. Increases in stock numbers are believed to be caused by use of groundwater in about 1895 which allowed for wider pastoral distribution of sheep into the interior.

To assess the impacts of pastoralism in Queensland, the historical records for each year were required to be captured based on estimates of the spatial boundaries. By digital manipulation of the spatial records contained by the QSS, an average stocking rate for each District can be calculated from 1860 onwards within Queensland. However, these Districts are large and variable. To understand the true impact of grazing on any particular area of land this datum must be disaggregated based on probable landscape conditions and redistributed by a stock distribution model (SDM). This would enable a spatial aspect to the livestock record for any given year, allowing for any area based investigation to be undertaken within Queensland to previous stocking impacts. This paper presents an example of such an approach for the Brigalow Belt North (BBN) bioregion for the period 1860 to 1949. This period was chosen for the study as the BBN contained significant stock numbers from 1860 until the mid-1940's. Grazing in this area was reliant on native unimproved pastures making it more suitable for any analysis involving pre-European vegetation assessments.

MATERIALS AND METHODS

In order to determine a historical grazing rate, four steps were undertaken:

1. Create and document changes to the mapping units employed by the QSS from 1860 to 1949;
2. Convert published stock numbers to stock units (adult equivalents);
3. Development of a stock distribution model (SDM); and
4. Distribution of stock units to finer scale mapping units across the landscape.

STEP 1. THE MAPPING OF THE QSS DISTRICTS

The QSS districts reflect the practice of European distribution of crown land that was being implemented at settlement. The Crown Lands Unauthorized (sic) Occupation Act 1836 (NSW) enabled all unsettled lands to be divided into a number of Pastoral Districts, each under the control of a Commissioner of Crown Lands. Later, with the Waste Lands Occupation Act 1846 (IMP), all land was further divided into three categories (unsettled, immediate and settled) each representing the nature of settlement at the time.

Accordingly, any new land was declared a Pastoral District and was further divided into districts according to categorical tenure divisions which in time were further divided into individual parcels. FIG. 1 is a map of all the pastoral districts that were formed prior to 1860 including the districts proclaimed prior to the separation of the colony of Queensland from New South Wales. It should be noted that the exact boundaries of the Pastoral Districts during this period is uncertain, given that early boundaries were not surveyed and only described to general terms. When Queensland became a separate colony in 1859, the division of crown land continued in accordance to the land acts, Tenders for Crown Lands Act 1860 (Qld) and Unoccupied Crown Lands Occupation Act 1860 (Qld), which were similar to those adopted in the

TABLE 1. QSS Mapping Exceptions, the suffix (A or B) indicates a similar named district but having a differing spatial extent.

District	Period	Explanation
Bollon A	1885-1892	Estimated from Bollon B (1899-1941)
Charlestown	1883-1885	Estimated division of Etheridge A
Etheridge A	1872-1883	Estimated as southern portion of Cook Pastoral District
Georgetown	1883-1885	Estimated division of Etheridge A
Mareeba	1895-1909	Data included into Thornborough
Moonie	1885-1891	Data included into Goondiwindi
Murphy's Creek	1882-1884	Eastern boundary estimated
Rockhampton	1860-1863	Western boundary estimated
Princhester	1863-1865	Estimated from surrounding district boundaries
Sandgate	1866-1872	Data included into Brisbane
Southwood	1899-1905	Data included into Goondiwindi
Thursday Island	1940-1946	Data included into Cook
Townshed	1917-1920	Data included into St Lawrence
Warraba	1867-1868	Data included into Brisbane
Waverly	1865-1866	Estimated from surrounding district boundaries
Wowan	1921	Data included into Rockhampton

New South Wales colony. The QSS showed a number of Police Districts (QPD) within declared settled districts, along with the Pastoral Districts. QPD can be seen as areas that have been declared as settled; whist Pastoral Districts were largely in the process of land distribution either as declaration of squatter entitlements or as free selection. By the end of 1882, the single remaining Pastoral District of Burke (formed in 1865) was sub-divided into QPD. The pattern of land tenure was changed with the passing of the Crown Land Act 1884 (Qld), where smaller squatter "runs" were consolidated and pastoral leases were issued as opposed to licenses to occupy.

A number of historical mapping sources were used to determine the spatial extents of the QSS. The record of boundary change was described only in general terms and often as an individual gazettal description, for example, some gazettal notices quoted a "telegraph line" as a boundary making it difficult to represent spatially. Though not attempted in this paper, it would be possible to estimate livestock distribution from these gazettal records. In addition a number of QSS districts could not be fully delineated due to the lack of any known mapping source. These districts have been estimated either by a boundary, or by examination of surrounding districts. In some cases districts have not been mapped and subsequently the statistical data was included into a surrounding pre-existing surrounding district (TABLE 1).

By investigating the process of subdivision and/ or consolidation of individual polygons of local government areas, the individual QSS areas could be determined and a base spatial extent for 1860 established. Therefore the QSS mapping presented for 1860 and subsequent years is a representation and not the actual boundaries, bearing in mind that the exact actual boundaries in some cases were not accurate and in some cases had not even been surveyed. From the methods described, a raster was created for each year from 1860-1949, allowing for analysis of the QSS to take place for individual years. Pastoral Districts are a cadastral based dataset and the QSS boundaries are the result of sub-division of the original Pastoral Districts. Therefore to construct an accurate baseline, the mapping has been based on a recent version of Queensland Digital Cadastral Database (DCDB) (Queensland Department of Environment and Resource Management 2011) that has been modified by merging individual Local Authority boundaries and creating a spatial estimate to the original Pastoral Districts.

New mapping units were created with expanding settlements each new sub-division would have incorporated small scale adjustments (at the property level) as a more detailed study of the survey record and gazettal notices would have shown. However, given the broad nature of this study, these effects would have had minimal effects on the results. Ham (1871) provided a spatial record to the QPD in the settled areas and these boundaries were drawn by geo-referencing the scanned map (captured at 1:2.5 Million) and vectors physically drawn within the 1860 base Pastoral District map. Additional Pastoral District boundaries were added to an individual yearly map when recorded in the QSS. FIG. 3 is presented to demonstrate the number of mapping units and the mapping source that was used across Queensland for this investigation.

QSS DISTRICT MAPPING 1860-1891

From the 1860 baseline, the QSS mapping during 1860 to 1891 is based on the following:

1. 1860 to 1871 Map of Queensland, Ham (1871);
2. 1872 to 1891 Commissioner of Railways Map (1913)
3. Queensland map of census districts and sub-districts (Registrar General of Queensland 1892) for boundary estimates in south-east Queensland from 1883-1885.

The mapping of QPD from 1872 was achieved by the examination and any associated changes contained in the Queensland Map of 1911-1912 (Commissioner for Railways 1913). These changes were drawn by geo-referencing the Commissioner of Railways Map (1913) (captured at 1:2.5 Million) and vectors physically drawn within the relevant base maps. QPD from 1885 to 1891 were seen as more representative of the Queensland Map of 1911-1912 (Commissioner for Railways 1913) due to a re-organisation of a number of QPD where an additional thirty-two districts were added in 1883-1885. In some cases the mapping from the Registrar General of Queensland (1892) was used to estimate some boundaries from 1883 onwards particularly within South-East Queensland for any boundary changes to 1891.

QSS DISTRICT MAPPING 1892-1939

The mapping was succeeded by Queensland Court of Petty Session Districts (QCPSD) from 1892, due to the enacting of the Stock Return Act 1893 (Qld) that allowed for the collection of stock returns for both statistical purposes and assessment of levies to be coordinated by the Courts of Petty Sessions (Daly, 1994).

The QSS mapping during 1892 to 1949 is based on the following:

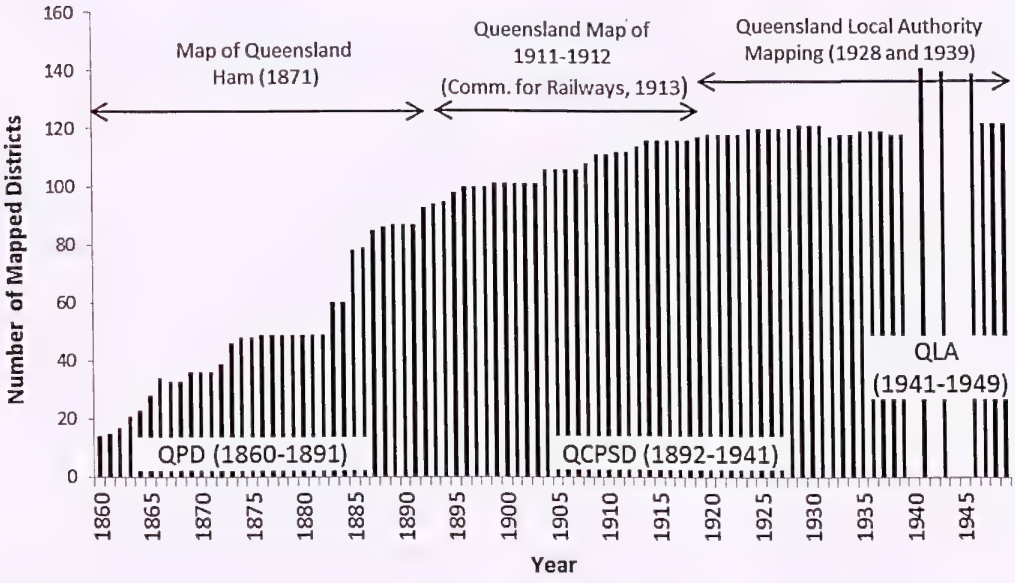

FIG. 3. The number of mapped statistical districts from 1860 to 1949 and the mapping source used for the spatial determination. Statistics for the years 1940, 1942 and 1944 to 1945 were collected and presented as state totals but not published for districts.

1. 1892 to 1918 Commissioner of Railways Map (1913);
2. 1919 to 1925 Queensland Royal Commission on Local Authority Boundaries (1928) (used for any boundary changes);
3. 1926 to 1934 Survey Office Department of Public Lands (1926);
4. 1935 to 1938 Survey Office Department of Public Lands (1935); and
5. 1939 Queensland Year Book (1939) (map showing local authority boundaries) (used for any additional boundary changes to 1940.

Examination of the QSS from 1891 to 1892 showed no significant changes to the number of reporting districts and it has been assumed that police district boundaries were similar to the court of petty session's boundaries. It is believed, that the gazettal of the Stock Return Act 1893 (Qld), changed the administration arrangements but reporting continued within the established districts from 1892. From this this basis it is assumed that these districts simply followed the previous boundaries of the QPD.

QSS DISTRICT MAPPING 1941-1949

After 1918, the QCPSD started to reflect and in some cases superseded by the Queensland Local Authority (QLA) mapping although the statistics of Queensland in part kept reporting individual QCPSD. However, after 1940, QSS was entirely based on QLA. The mapping was based on Gutteridge (2001).

STEP 2. CONVERSION OF STOCK NUMBERS TO ADULT EQUIVALENTS

The sheep, cattle and horse numbers for each QSS district were manually entered, checked against the published Queensland yearly state totals and a further analysis on individual QSS time series performed. A number of animal type ratios were calculated and yearly district stock totals were also examined as a further check for potential data errors. Averages for sheep, cattle and horses number were substituted for the calendar years of 1940, 1942, 1944 and 1945 as this data was not published for individual districts; and in cases of missing district data.

In order to quantify the possible grazing impacts of horses, cattle and sheep, dry adult equivalents (AE) are used where horse and sheep numbers are converted to approximate cattle numbers. In this study, an AE is defined as a 450 kg animal and an assumption has been made that the QSS cattle and horse numbers reflect this estimate (Stone, 2004). The QSS stocking statistics do not indicate the actual weights or age of the animals for the whole period being examined. Stone (2004) however, lists additional factors that would be required for an accurate cattle assessment. Therefore, quantifying cattle body weight over time is difficult in the absence of comprehensive records which the QSS alone does not provide.

The conversion of sheep number to an AE is also problematic as Stone (2004) highlights. In summary early AE estimates used 10 dry sheep equivalents (DSE) per AE. Thereafter, given increases to sheep and wool weights are more akin to 7 DSE per AE in modern times. Calculating DSE from historic data records like the AE calculation can only be an estimate due to the absence of relevant data pertaining to live weighs gains of all stock, herd composition and trends in slaughter age and weights. For this paper the following expression has been used that attempts to reflect a DSE estimate in each year of the QSS studied where:

Equation 1: $DSE\ AE^{-1} = Sheep\ Number / 7$

Stone (2004) also concludes that a horse equivalent would be equal to cattle, quoting that the feed intake of the average work horse is similar to adult cattle, which allows for the AE for each QSS district for each year to be calculated as:

Equation 2: $LS = DSE\ AE^{-1} + Cattle\ Numbers + Horse\ Numbers$

STEP 3. DEVELOPMEMNT OF THE STOCK DISTRIBUTION MODEL

As shown in FIG. 4, the information to construct the SDM was:

1. Draft pre-clearing regional ecosystems (PRE) (Queensland Herbarium 2010);
2. 2003 Foliage Projective Cover (FPC) Mosaic (Department of Environment and Resource Management 2003);
3. One second SRTM Derived Digital Elevation Model (DEM) (Geoscience Australia 2010); and
4. Collaborative Australia Protected Area Database (a) 1860-1889 or (b) 1890-1919 or (c) 1920-1929 or (d) 1930-1939 or (e) 1940-1949 (Australian Government 2008)

TABLE 2. The original attributes of the spatial information sets used in the study.

Spatial Information	Format and Scale	Coordinate System	Linear Unit
QSS and Protected Areas (a,b,c,d and e)	Vector, various scales based on the current Queensland Digital Cadastral Database (DCDB). Protected areas based on Collaborative Australia Protected Area Database (2008).		
PRE	Vector, 1:100,000 to 1:250,000	Geographic Coordinate System Geocentric Datum of Australia 1994	Degrees
FPC	Raster 25 metre pixel	Albers Conical Equal Area Geocentric Datum of Australia 1994	Metres
DEM	Raster 30 metre (1 second) pixel	Geographic Coordinate System World Geodetic System 1984	Degrees

All spatial information sets were converted to raster (where applicable), resampled using cell center values to a 100m pixel (the lowest scale being the FPC at 25m pixel) and projected to Geocentric Datum of Australia Geoscience Australia Lambert. TABLE 2, provides the characteristics of the spatial information sets used in the calculation. Categorical decisions based on vegetation density (from PRE) and slope (Digital Elevation Model DEM) divided the SDM into four grazing land (GL) categories being:

1. Pastures (GL1);
2. Open Woodlands(GL2);
3. Woodlands and Forest (GL3); and
4. Dense or Steep Lands (GL4).

After raster conversion, a number of attribute selections were made within the PRE, FPC and DEM (FIG. 4). The PRE was used to determine the natural potential pastures areas where settlement favored for pastoral development. The most likely areas where livestock would have been concentrated during initial settlement were determined by selecting the grassland, sparsely wooded and mid-dense vegetation communities of the PRE. The categories are based on an estimate of likely grazing pressure based on native vegetation structure, foliage projective cover and slope. The criteria were used to designated either lands that were able to be grazed freely (GL1) as well as restrictive areas (GL3 and GL4).

The FPC, DEM and protected lands were used to improve the accuracy of the SDM. It was assumed that wooded areas (FPC 30 to 89%) would have reduced levels of grazing while dense (FPC >90%), closed or steep lands would have minimal grazing. The DEM was used to delineate steep lands where slope occurs above 35 degrees. Areas of native pastures (GL1) or wooded/forest (GL3) that overlapped either wooded/ forest (GL3) or dense or steep lands (GL4) were substituted as GL4. All areas not affected by any of the spatial selections were designated as open woodlands (GL2.). The protected lands information set is cadastral based information used to locate areas that would have lowered livestock numbers. The protected lands were determined primarily from the Collaborative Australia Protected Area Database (Australian Government 2008) that was geo-referenced to the Queensland DCDB, followed by infilling of missing secondary data (i.e. the default year of 1890 representing the first Queensland National Parks gazettal) (Carter, pers. comm.). The protected lands information set has been divided into five time periods, (a) up-to 1890 where the eastern sandy islands closest to early settlement were known to be unsuitable for grazing; (b) where 92 instances of protected land were declared from 1890-1919 and 16 records from (c) 1920 to 1929, (d) 1930-1939 and (e) 1940-1949. These areas were designated as GL4. Each GL is assigned a percentage base weight (w). The following percentage based values (w) were applied to the following grazing lands (GL): where GL1 = 100, GL2 = 60, GL3= 40 and GL4 = 0. To represent the changes caused by the increase in protected areas (w = 0), it was necessary to create five rasters representing the SDM for the following calendar years; (a) 1860 to 1889, (b) 1890 to 1919, (c) 1920 to 1929, (d) 1930 to 1939 and (e) 1940 to 1949. The SDM was created by combining the intermediate rasters and substituting the lowest

value where pixels of a different raster that is overlaid. The intermediate raster datasets, native pastures, open woodlands, woodlands/forest and dense steep lands, were reclassified to reflect the proportion of grazing pressures.

STEP 4. THE DISTRIBUTION OF STOCK

To estimate a yearly stocking rate (SR) from 1860 to 1949, three rasters were prepared in ArcGIS 10.2 for each calendar year (n) being:

- SDM - The Stock Distribution Model (FIG. 4).
- QSS_Area - The area (ha) of the individual QSS; and
- LS - The livestock estimate (AE) per QSS district based on Equation. 2.

FIG. 5 is a summary that shows the sequence of raster calculations made for each calendar year (n) that allows a stocking rate estimate to be made at the individual pixel, independent of statistical boundaries allowing for a calendar year stock rate to be calculated for any area of interest within the study. The following immediate values (as rasters) were required, where a raster for each n was created for:

- GL_Area - The weighted percentage area (ha) of grazing lands. The area (ha) of the GL was multiplied by its weight (w) and divided by 100;
- DC - The district capacity of each QSS district. The DC for each QSS is the total of all GL_Areas; and
- CC - The stocking capacity index. This is calculated by DC being divided by GL_Area.

In each GL_Area raster, the area (ha) of GL1, GL2 and GL3 was multiplied by w and then divided by the District Capacity (DC) - being the sum of area of GL1, w.GL2 and w.GL3), where:

Equation 3: CC = (Area GL1 + 0.6*Area GL2 + 0.4*Area GL3) / DC

A Python script was employed to calculate DC for each QSS and a calendar raster produced. FIG. 6 provides

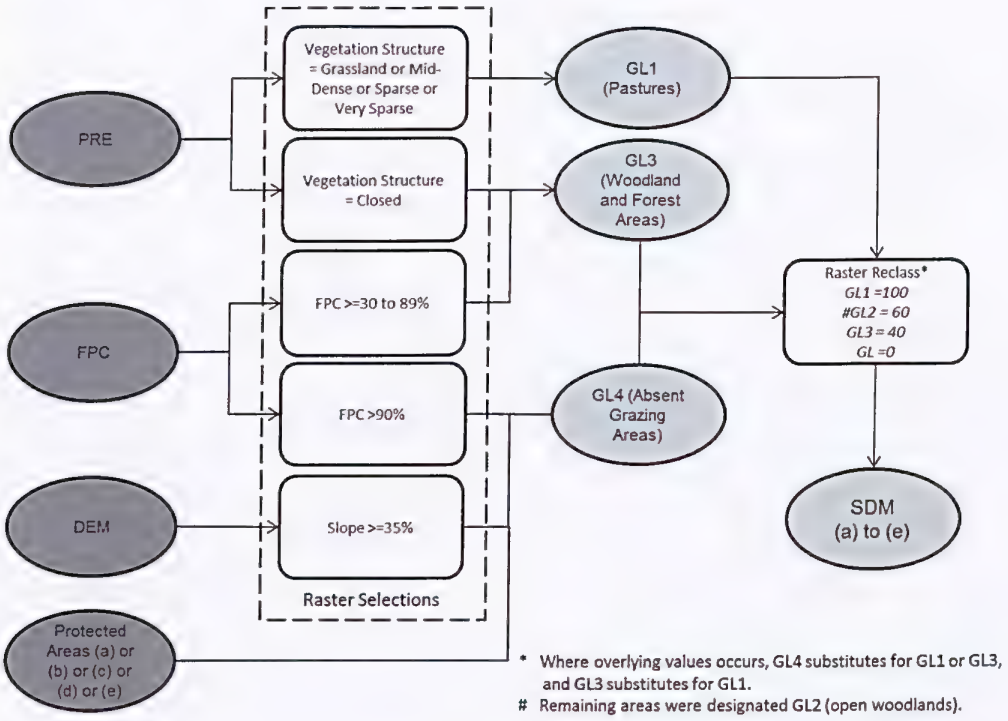
PRE
FPC
DEM
Protected Areas (a) or (b) or (c) or (d) or (e)
Vegetation Structure = Grassland or Mid-Dense or Sparse or Very Sparse
Vegetation Structure = Closed
FPC >=30 to 89%
FPC >90%
Slope >=35%
Raster Selections
GL1 (Pastures)
GL3 (Woodland and Forest Areas)
GL4 (Absent Grazing Areas)
Raster Reclass*
GL1 =100
#GL2 = 60
GL3 = 40
GL =0
SDM (a) to (e)
* Where overlying values occurs, GL4 substitutes for GL1 or GL3, and GL3 substitutes for GL1.
# Remaining areas were designated GL2 (open woodlands).

FIG. 4. The concept and creation of the Stocking Distribution Model (SDM) used in this study.

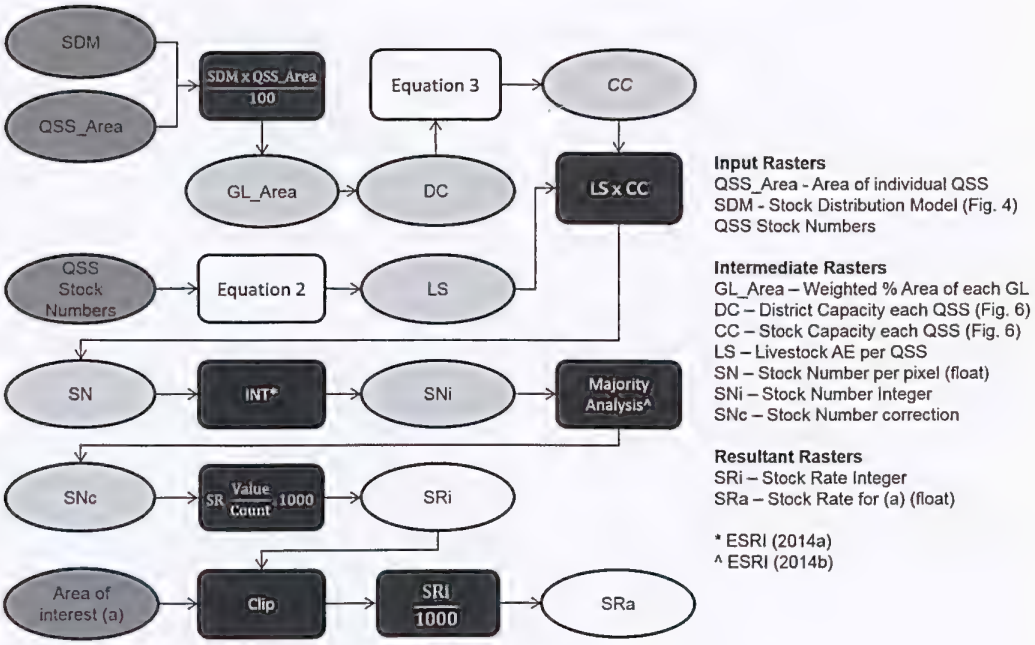

FIG. 5. The process employed to determine an estimated stocking rate for an area of interest.

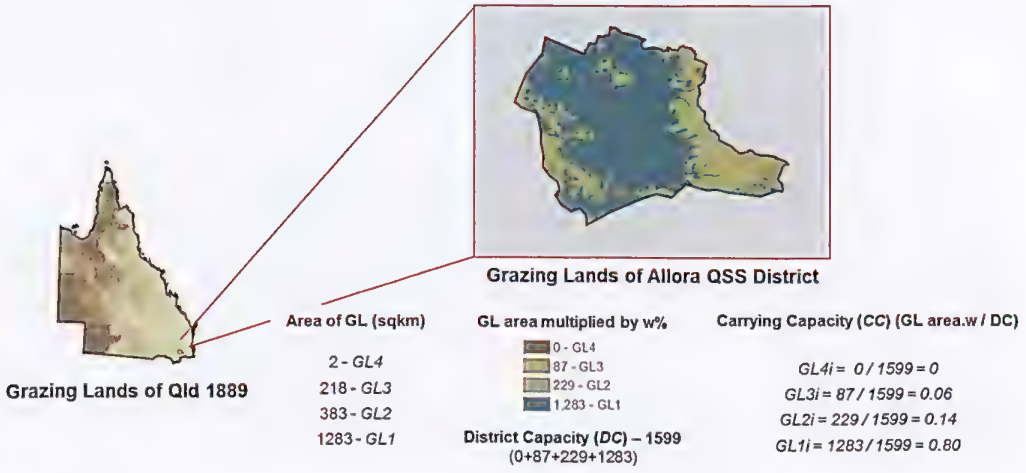
Grazing Lands of Allora QSS District
Grazing Lands of Qld 1889
Area of GL (sqkm)
2 - GL4
218 - GL3
383 - GL2
1283 - GL1
GL area multiplied by w%
0 - GL4
87 - GL3
229 - GL2
1,283 - GL1
District Capacity (DC) – 1599
(0+87+229+1283)
Carrying Capacity (CC) (GL area.w / DC)
GL4i = 0 / 1599 = 0
GL3i = 87 / 1599 = 0.06
GL2i = 229 / 1599 = 0.14
GL1i = 1283 / 1599 = 0.80

FIG. 6. Example calculation of district capacity (DC), grazing land areas (GL) and carrying capacity (CC) for the Allora District for 1889.

an example where the DC and GL calculations for the Allora QSS district for 1889 are shown. To calculate QSS Area and GL Area, each raster was converted to floating point. By dividing the DC to the GL_Area, the CC raster was created which represents all GL for a specific calendar year. By multiplying the LS and CC, a stock number for each pixel was calculated (SN).

The SNi (an integer based SN) contained a number of erroneous pixel values at locations from intersections from the input vector datasets. To correct these values, the majority analysis tool was used at a circular radius of 10 pixels (approximate area of 62.50 ha) in order to substitute the error values to a dominant average, creating the SNc raster. The SNc is later divided by the value and count of the individual pixels and multiplied by 1000 in order to return an integer based stock rate per pixel (SRi). Subsequent division by 1000 within the area of interest clip (a) calculates a stock rate where each pixel is 1 hectare in area, giving the final result in AE ha^{-1} (SRa). Within the calendar rasters, the SR total when compared the LS total was generally higher but were highly correlated $R^2 = 0.9981$, suggesting that the statistical majority function has caused the difference from the total LS and SR. The truncation of cell values used to convert floating values to an integer (ESRI 2014b), is also a source of the differing totals. However SNi was expected to be lower than SN but in these instances there was a low count (generally less than 100 pixels). Whilst a modification based on the correlation may have been used, the effect of the overall grazing rates would have been minimal due to the extent of the study area and not applied in this exercise.

RESULTS

The stock numbers calculated prior to redistribution have been transferred to the AussieGrass (Carter *et al.* 2000) repository providing a Queensland livestock records back to 1860. The use of the SDM and redistribution of this data is demonstrated for a historical time period within the Brigalow Belt North (BBN) - Interim Biogeographic Regionalisation for Australia (IBRA) (Australian Government 2012). The data shown in FIG. 7 have been adjusted to compensate for estimates stock weight and herd characteristics in order to create a continuous record for AussieGRASS (Carter *et al.* 2000). This methodology is presented and discussed in Carter *et al.* (1996). The BBN has been extensively studied for land development purposes as summarised by the Royal Society of Queensland (1982). Therefore, vegetation and other landscape attributes are relatively known for the time period examined for the PRE and adequate enough to determine a grazing distribution for the BBN. The results of the distribution methodology are shown in FIG. 8, where the distribution of stock has been calculated by an average stocking rate for an area of $10km^2$. FIG. 8 shows 1894 and 1939 as the times of peak grazing.

DISCUSSION

The results show how historical stock numbers correspond with the cyclic nature of drought. Foley (1957) estimated severe droughts occurred in the North Coast (Townsville and Charters Towers) and the Central Highlands area during 1883-1886, 1899-1903, 1913-1916 and 1926. These years correspond and match the low stock numbers estimated in 1885, 1903, 1916 and 1927. A moderate drought recorded

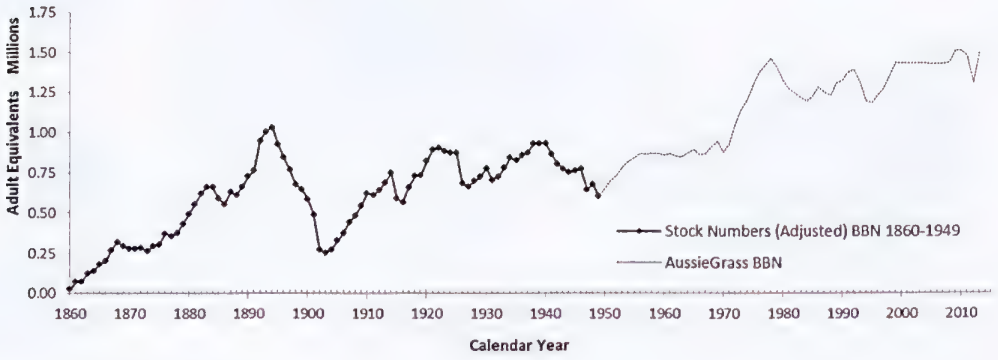

FIG. 7. The yearly total Adult Equivalents estimated for the Brigalow Belt North Bioregion (IBRA) from 1860 to 2013.

after 1946-1947 appears to have combined with post-war economic conditions as the causation of low stock numbers. An additional dry period during from 1868 to 1878 was noted to have caused a temporary halt to pastoral expansion (Holmes 1966) and the stock numbers are similar to the federation drought of 1899-1903. The low rainfall condition of the decade during 1870 has been observed by Palmer *et al.* (2015) comparable to the areas of the BBN.

The methods described in Carter *et al.* (1996) were employed as a check for the Brigalow Belt North Bioregion (IBRA) from 1860 to 1949 and differences to the stock estimates were seen from 1910 to 1949. The differences observed are reflective of the uncertainties due to the estimates for Foliage Projective Cover prior to remote sensing technology, adequate land use data resulting in differing distribution methodologies and the AE estimates employed. However, there is general agreement of the total stock numbers between the methods from 1860 to 1910. Therefore, the PRE can only give an estimation of areas, due to the absence of other consistent information and can only be used at large scales. The information presented here is best used at higher scales (>1:250,000).

Daly (1994) questioned the accuracy of the QSS livestock statistics, particularly the earliest records, due to the government's intention and methods for the collection of the records. The information at various times was collected to determine various levies, hence the possibility of individual properties reporting lower stock numbers. According to Daly (1994) stock inspectors (under the auspices of the Chief Inspector of Stock - Lands Department 1869-1871, subsequently the Colonial Secretary's Department to 1892) collected statistics in order to calculate monies under a succession of Queensland legislation including the Diseases in Sheep Act 1867 (Qld), the Brands Act 1872 (Qld), the Marsupial Destruction Act 1892 (Qld) and the Rabbit Board Act 1891 (Qld). In many cases, stock statistics for a particular area

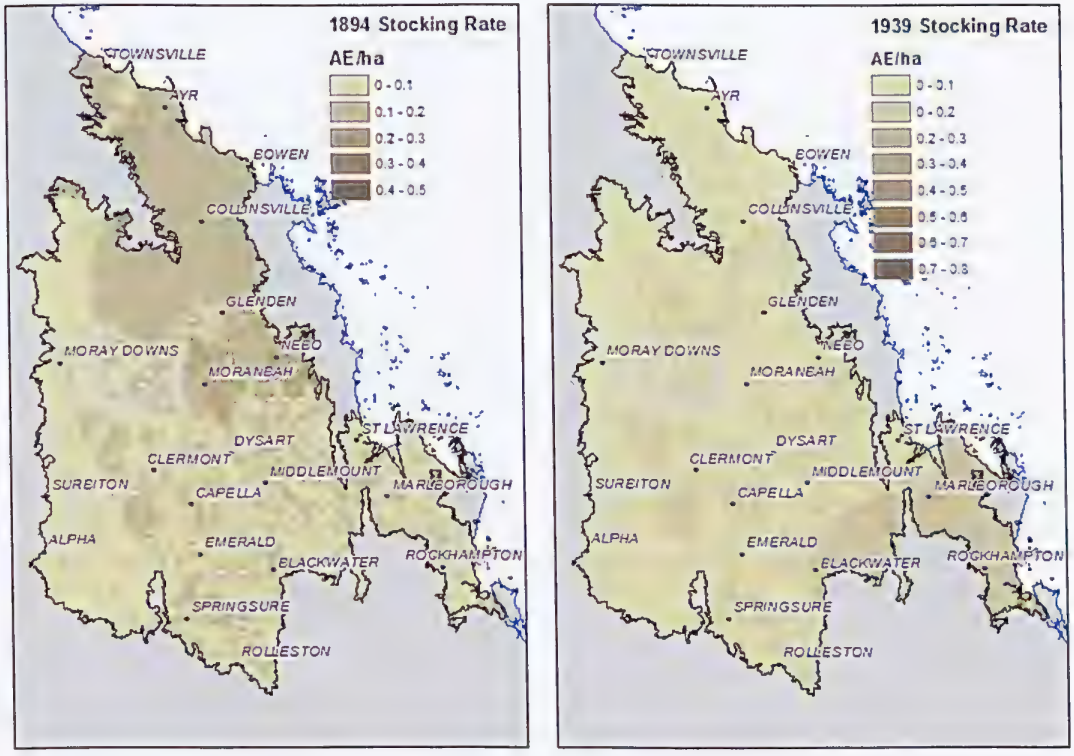

FIG. 8. A comparison of estimated stocking rates during the peak grazing calendar years of 1894 and 1939 for the Brigalow Belt North (IBRA).

were collected by more than one source, increasing the potential for error. Despite the police visiting properties to collect information from 1860 to 1891 (Daly, 1994), the pioneering nature of settlement (i.e. unfenced properties, squatter and chaotic stock movements) and the effects of floods and droughts, would have hindered the collection of accurate data.

There is additional uncertainty about the composition of stock in the QSS and the conversion to AEs. Under the provisions of the Stock Returns Act 1893 (Qld), data were collected where the individual proprietor owns one or more sheep, ten or more horses, ten or more horned cattle, or ten or more horses and cattle combined (Queensland State Archives 2012). Therefore, the record does not account for differences in herd composition that would affect pasture utilisation. Daly (1983) noted that cows represent 53% and steers and bullocks averaging 29% of the herd during the 1940's to 1950's. More accurate AE conversion could be achieved by applying an average herd adjustment for cattle where data is available. The use of predictive statistics in areas of no records also could be potentially used in order to ascertain the unofficial stock movements during the 1840's to 1870's. A number of historical references refer to grazing activities in areas with no records in the QSS or were occurring at times prior to official settlement. As an example a general description of pioneer and squatter occupation is given for the Burdekin Catchment (Lewis *et al.* 2007). Predictive techniques similar to Robinson *et al.* (2014), based on covariants covering water sources, distance and transport corridors (Crown Land and Survey Office 1872) could be used in areas where there are no QSS data.

A comparison to the SDM as made to the modelling methodology employed by the Gridded Livestock of the World (GLW) (Robinson *et al.* 2014) albeit the temporal differences and animal factors. There are some similarities, particularly the use of vegetation indicators, protected lands and topographic information. The GLW used a topographic limit of 40% slope and made use of climatic and seasonal vegetation indices in order to estimate stock movements due to seasons. The SDM is a simpler model due to the lack of remote sensed data and is dependent on a vegetation density estimate from the PRE which in turn is based on expert opinion (Queensland Herbarium 2010). Seasonal effects within the calendar year are not considered, although further work in determining rainfall patterns between yearly stocking rates is a consideration for improvement to the SDM. Due to the simplicity of the SDM and restrictive data, there was no further disaggregation of livestock densities to lower scales.

Improvements to the SDM can also be made by increasing grazing priority to that on the surface water and its relevant distance, as historical references point to initial grazing leases being positioned to prime surface water area, prior to the utilisation of ground water resources in the mid 1890's (Anon. 1899, Allingham 1977, Archer 1972, De Satge 1901 and May 1984). Harrington *et al.* (1979), wrote that by 1866 virtually all the frontage country on the Warrego and Culgoa/Balonne Rivers have been developed for grazing but it was until 1879 that the waterless hinterland was occupied. Anon. (1899), confirms that within the Peak Downs, where the early squatters had the opportunity to acquire the pick of the fine downs (basaltic) country, they (instead) went into the timbered country afforded by water, due to the lack of knowledge of the local climate and water supplies. According to Collyer (1991), de Satge (1901) and Anon (1899) the majority of early pastoralists did not attempt to improve the land, as there were ample unoccupied grasslands and open woodlands. After the lands became occupied ring-barking and clearing of scrub became a common land improvement tool. A map of Southern and Central Queensland provided by Crown Land and Survey Office (1872) shows surveyed properties being centered on major water courses, evidence that a reliable water supply was essential to initial settlement.

Vegetation change since settlement has not been measured, however wide spread use of ring barking in closer settlement areas (Collyer 1991), Maranoa and Atherton Tablelands in 1880-1930s may have had an impact. However, possible errors in the estimation of vegetation density from the regional ecosystem mapping cannot be discounted. No attempt has been made to calculate vegetation thickening prior to 1949 (Burrows *et al.* 2002; Fensham and Holman 1998) and vegetation regrowth resulting from the known clearing.

In Lewis *et al.* (2007), the QSS stock statistics were used for a similar period but were simply combined into Burdekin River sub-catchments without taking into account the statistic boundaries, adult weights, or vegetation differences. Consequently, by not considering statistical area boundaries and

incorporating outside point sources Lewis *et al.* (2007) may have overestimated the stock numbers in the Burdekin. However, even though this paper has partly addressed Daly's (1994) accuracy concerns, the QSS records used in this study still do not account for squatter settlements and associated stock numbers.

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AUTHOR PROFILE

Scott Irvine is a scientist with the Department of Science, Information Technology and Innovation working with Grazing Land Systems. He has been employed by the Queensland Government in various geographic and scientific roles since 1995. First employed as a land resource officer, Scott has since extended his work experience into soil science, vegetation management, geographical information systems and grazing research, throughout central Queensland along with his personal interest in history.

REHABILITATION OF LAND DISTURBED BY MINING AND EXTRACTIVE INDUSTRIES IN QUEENSLAND: SOME NEEDED LEGISLATIVE AND MANAGEMENT REFORMS

MARLOW, D.

The rehabilitation of mined and drilled land in Australia is a state responsibility. Consequently, each state and territory has its own legislative, tenure allocation, oversight and management regime. This structure of disparate regimes poses problems for companies operating across jurisdictions, but it does have the advantage that if a state is serious about improving its site rehabilitation regime, it has the opportunity to 'cherry-pick' from the best of that of the other states, as well as from overseas. Operators would coincidentally benefit from a greater commonality of legislation. The Queensland government could significantly improve its approach to site rehabilitation by the following: analyse past relevant government reports to see if unadopted recommendations should regain current attention, mandate progressive rehabilitation as standard practice, mandate a requirement for a mine closure plan prior to approval of a resource lease, establish a single team to regulate rehabilitation on all sites, treat all abandoned sites in the same way, close legal loopholes for evading site rehabilitation and implement legislative changes to increase funding for site rehabilitation.

The word "mine" in this paper includes oil, natural gas and CSG (coal seam gas) wells.

INTRODUCTION

Queensland presently faces large and greatly increasing environmental problems, resulting from past and present mining activities. Some abandoned mines cause severe acid drainage contamination, while modern open-cut mining operations create massive landform alterations. At the Peak Downs open-cut coal mine alone, about 31 million bank cubic metres of overburden are moved annually, while at the neighbouring Saraji mine, about 42 million bank cubic metres are excavated annually (Foster, 2013). FIG. 1 illustrates the scale of operations.

The Queensland public probably expects that all sites (abandoned, surrendered, or operational) will eventually be rehabilitated. However, the public's understanding of what this means in reality is not necessarily that of governments, public servants, or mine operators. The public probably expects that all sites will be restored to a state approximating what existed prior to operations, or at least to a landform that is safe and stable for cattle to graze and where pollutants will not contaminate groundwater or surrounding lands and waterways. However, the cost of achieving this standard is staggering. The cost to taxpayers just to rehabilitate all abandoned sites to this standard may be anywhere between a billion dollars and ten or even twenty billion dollars. The cost of doing so for operational sites is far higher. Queensland currently holds 5.38 billion dollars in rehabilitation securities, but the true rehabilitation cost may be anywhere between fifteen and fifty billion dollars (Australian Broadcasting Corporation 2015a).

This paper describes the magnitude of the present rehabilitation problem - the onerous costs and the inadequate funds. It then offers several proposals on how we might improve our management of the problem and so be more efficient and effective in our rehabilitation efforts. Finally, it offers several proposals on how additional funding might be obtained to increase the size of the rehabilitation effort.

The objective of the paper is to generate discussion on an integrated suite of management, regulatory and legislative reforms that will dramatically improve the future natural environment of Queensland, compared with the worrying future resulting from incomplete rehabilitation of mine sites.

ENVIRONMENTAL PROBLEMS: A BRIEF EXPLANATION

ABANDONED SITES

The principal environmental problem on abandoned sites is that of *acid mine (or rock) drainage*, which can be defined as all processes where the inadvertent oxidation of sulphide-bearing rock following mining leads to the release of pollutants. FIG. 2 displays the distinctive blue colour of copper sulphate leachate in an acid mine drainage spill. The oxidation of

sulphidic mine wastes and the consequent release of acid drainage is one of the main strategic environmental issues facing the mining industry (Harries, 1997). Large quantities of excavated rock containing sulphide minerals interact with water and oxygen to create sulphuric acid and the interaction can occur in tailings dams, spoil heaps, pit walls and underground workings. This can leach or flow into streams and aquifers. The increased water acidity caused by these leachates is often fatal to wildlife, including stygofauna in aquifers and aquatic life in streams – especially following major breaches of any containment system. However, the deleterious environmental effects of major one-off acid-water incidents are often temporary.

A greater and more persistent problem is that of associated heavy metal contamination. The excavated sulphidic rock often contains heavy metals, such as arsenic, cadmium, cobalt, copper, lead, silver and zinc. The acidified water mobilises these elements and carries them downstream. These toxic metals accumulate in the food chain and can prove lethal. The metals are transported as either dissolved species in water (the more dangerous form) or as an integral part of suspended sediments. They may then be stored in river bed sediments or seep into the underground water, thereby contaminating water from underground sources, particularly wells (Duruibe, Ogwuegbu and Egwurugwu, 2007). Heavy metal contamination is persistent. For example, the Rio Tinto orebodies in Spain have been mined since the third millennium BC. Leblanc et al (2000) believe that 'long-term release of metals from ancient mining operations that have not received the benefit of modern remediation may be a more serious problem than the impact of much larger, modern-day operations'.

OPERATIONAL SITES

Open-cut mines can create massive unnatural landforms. A modern open-cut coal mine may be 40 km long and may cut to a depth of 300 m. The extraction process creates massive spoil heaps with steep erosion-prone slopes and leaves massive voids that accumulate contaminated water. Major flood events can flush the contamination into nearby waterways.

FIG. 1. Peak Downs and Saraji coal mine, Queensland, 2012 (Image source: Lock the Gate Alliance).

In 2010, the National Water Commission (2012) warned that the CSG industry needed to be adequately managed and regulated to avoid the risk of significant long-term impacts on adjacent surface and groundwater systems. The Commission was concerned that 'CSG development represents a substantial risk to sustainable water management, given the combination of material uncertainty about water impacts, the significance of potential impacts, and the long time period over which they may emerge and continue to have effect'. The potential risks included permanent damage to aquifers, resulting from excessive water extraction, depressurisation, cross-contamination and the re-injection of treated waste water.

ONEROUS COSTS - INADEQUATE FUNDS

ABANDONED SITES, LEGACY SITES AND DERELICT SITES

In Queensland, an abandoned mine is defined as a former mining site where a mining tenure no longer exists and there are no legal avenues requiring the company or individuals that created the disturbance to carry out remediation (QG, 2015a). A legacy site is defined as a site that has been closed, but continues to negatively impact the environment or nearby communities – the associated mining tenure may or may not still exist. An abandoned site may be a legacy site. In New South Wales, a derelict mine is defined as a former mining site requiring remediation, where no individual or company can be held responsible for its management or rehabilitation (Department of Industry Resources and Energy, n.d.).

Remediation of abandoned sites involves addressing site safety and health risks, as well as containing potential contaminant spills and discharges into streams (QG, 2015b). There are more than 15,000 identified abandoned mine sites in Queensland.

FIG. 2. Acid Mine Drainage impacted waters of the Dee River in the vicinity of the Mount Morgan mine site (Image source: Unger et al. 2003)

About 3,500 of them are on state-owned land (QG, 2015a). The Queensland government is responsible for those on state-owned land. However, it claims that private landholders are responsible for managing abandoned mines on their land, including the hazards that accompany them (QG, 2015b). A similar legal position is held by the New South Wales Government (Department of Industry Resources and Energy, n.d.). The Queensland government will take action on any of the approximately 12,000 abandoned mines on private land only if there is an identified associated public hazard (QFCE, 2012).

The QAO estimated that it will cost up to a billion dollars to rehabilitate all abandoned mines in Queensland (QAO, 2014). This may be a serious under-estimate. Dr. Erskine of the CMLR estimates that the cost of fully rehabilitating the Mount Morgan site alone would run 'probably in the hundreds of millions to [a] billion, in the billions probably' (Australian Broadcasting Corporation, 2015b). See FIG. 2. Tim Buckley, Director of Energy Finance Studies (Australasia) of the pro-renewable energy group Institute for Energy Economics and Financial Analysis, believes that the true figure of the cost of rehabilitating all abandoned mines in Queensland is more likely to be ten or twenty billion dollars (Seccombe, 2014). The Queensland government allocated $8.3 million in the 2016-17 budget for the task (Queensland Cabinet and Ministerial Directory, 2016).

OPERATIONAL SITES

Operational sites are sites where the site operator still has legal responsibilities. Such sites include 'care-and-maintenance' sites (where active resource extraction has been suspended and may later resume), sites in their closure stage, even post-closure sites (where long-term site monitoring or continuing treatment may be required).

QAO (2013-14) came to the following conclusions. There is a significant gap between the total financial assurance (bonds) held and the estimated cost of remediation and it is not possible to quantify the size of the gap. Successful environmental rehabilitation is not occurring and the state remains exposed to unnecessary financial risks. Financial assurance is usually forfeited to the state only when environmental authority holders go into liquidation. Even then, rehabilitation commonly does not occur, because the assurance is insufficient for this purpose.

IMPROVE MANAGEMENT

MAKE THE MOST OF PAST MAJOR REPORTS

Many legislative, management and enforcement deficiencies in site rehabilitation have been highlighted in important government reports, such as:

1. '*Environmental regulation of the resources and waste industries*' (QAO (2013-14));
2. '*Final Report of the Queensland Floods Commission of Enquiry*' (QFCE, 2012); *and*
3. '*Review of the Roles and Responsibilities of The Department of Natural Resources, Mines and Water Environmental Protection Agency and Department of Primary Industries and Fisheries*' (SDPC, 2007).

All three reports made cogent recommendations. Some have been implemented. Work may be underway on others. Some have not been adopted. The unadopted recommendations should be looked at, anew. It is far better to make as much use as possible of existing extensive reports by experienced authors, before embarking on expensive new lengthy enquiries. This paper will later address some of these unadopted recommendations.

The review task requires a fixed end date, progressive release of results and a relatively small project team, with the expertise to competently analyse most of the recommendations and the ability to call on outside experts for advice, where needed. This determination should be carried out by a government committee (just as departments now are required to tabulate progressive implementation of election promises) and the results published on the Queensland government website. If the government is reluctant, the task should be carried out at a public governance centre at a Queensland university, or by the Queensland branch of a reputable relevant professional organisation (such as the Royal Society of Queensland, or Engineers Australia, or the Australian Academy of Technology and Engineering).

MANDATE PROGRESSIVE SITE REHABILITATION

Rehabilitation work is carried out on mine sites, with mixed results, and valuable lessons are being learned:

1. The rehabilitation work at the Kidston gold mine in North Queensland was highlighted in a mine rehabilitation handbook that was developed by a working group of experts, industry, and government and non-government representatives (Australian Government 2006, p. 36). At Kidston, store/

release covers were constructed over all waste rock dumps to minimise erosion and facilitate revegetation by storing wet season rainfall and releasing it during the long dry season via evapo-transpiration.

2. The rehabilitation work at coal mine sites in central Queensland's Bowen Basin have been extensively studied, and the findings have largely been disappointing - 'The steeply sloped landforms, poor soil characteristics, depauperate native species pool, and uniform presence of exotic pasture grasses in the rehabilitation indicate that most of these newly created ecosystems should not be used for cattle grazing and also have few natural values' (Erskine and Fletcher, 2013).
3. The rehabilitation work at the Mount Leyshon open-pit gold mine in North Queensland was a combination of progressive and post-closure rehabilitation and was recognised with a Premier's award for environmental excellence. However, Dowd (2005) detailed deficiencies in the post-closure rehabilitation – some progressive rehabilitation was delayed until closure and contributed to exhausting the contingency budget allocated for the closure, the active site management required until the site was shown to be self-sustaining was not done and the monitoring needed to determine if the landscape had reached a self sustaining state was also not done. It cost several million dollars to go back and fix the work that had already been done. The lesson learned was that post-closure management needs to be given the same degree of attention as operational site management.

A progressive (staged) rehabilitation model is far superior to that of a rehabilitation-after-closure model. Progressive rehabilitation is carried out as part of daily operations in the early years, when cash flow is at its healthiest, the management structure is in place and on-site personnel and equipment are available to carry it out. A rehabilitation plan must therefore be in place at the start of operations and its implementation at the forefront of daily management decision-making.

Unfortunately, the usual practice is rehabilitation-after-closure. Justifications are given for this practice. The mining plan may change over time as more knowledge is gained of each ore body's spatial and grade distribution. The worth of the ore body might increase significantly over time, requiring rehabilitated areas to be dug up to regain access to the ore body – historically, this has occurred with gold mines. However, in the early mining days, resource companies simply walked away when the profits dried up. Dr. Erskine of the CMLR asserts that, to avoid repeating its past, Australia must ensure that operating mines are properly and progressively rehabilitated while they are turning a profit (Australian Broadcasting Corporation, 2015a). A site rehabilitation plan may not even be prepared until after closure, at a time of negative cash flow. The magnitude of site rehabilitation obligations may not even have been considered in the good times and now there may be neither the resources nor the will to fulfil those obligations.

If rehabilitation is delayed until after closure, there is the incentive never to formally close the site at all, but instead consign it (and its unfulfilled rehabilitation obligations) to the indefinite limbo of 'care and maintenance'. A site is in 'care and maintenance' if the environmental authority holder is no longer operating the site to produce resources, but is maintaining the site, infrastructure and equipment. A site may go into 'care and maintenance', because of a temporary downturn in world commodity prices. However, in some cases, particularly sites in care and maintenance for long periods, the operator may believe that full rehabilitation is unachievable or financially prohibitive and that indefinite 'care and maintenance' status can be used to indefinitely avoid rehabilitation (QAO, 2013-14). With continuing delay in even starting the rehabilitation process, there is also the continuing risk of bankruptcy and the transfer of rehabilitation obligations to government – or of operators convincing a government-of-the-day that it is now 'unreasonable' to have onerous rehabilitation obligations fulfilled. Dr. Erskine of the CMLR asserts that 'The Government doesn't want to take on the risk of a closed mine and the industry is reluctant to spend the money required to safely close the mine. Instead, what we see are mines placed into care and maintenance, where the mining companies can avoid paying out rehabilitation bonds, because the mine isn't officially closed' (Australian Broadcasting Corporation, 2015a).

Little progressive rehabilitation occurs in Queensland. The concept of progressive rehabilitation was

introduced into the Environmental Protection Act 1994 in 2006 and can reduce financial assurance by certifying areas as rehabilitated during the life of the environmental authority. DEHP has identified one case since 2006 where progressive rehabilitation had started (QAO, 2013-14).

It is thus time to move from progressive rehabilitation being 'encouraged' by government (with little visible sign of success) to progressive rehabilitation being mandated as standard practice for any mining operation – future and present. The regulating authority and site operator should jointly create a workable enforceable progressive rehabilitation plan for every site.

MAKE MINE CLOSURE PLANS A CONDITION OF DEVELOPMENT APPROVAL

Planning for mine closure is a critical component of environmental management in the mining industry. World's best practice requires that planning for mine closure start before mining commences and continue until final closure and relinquishment. This creates better environmental outcomes and should avoid the need for costly remedial earthworks late in the project life cycle (DMPEPA, 2015).

In Queensland, any proposed mining operation requires an Environmental Authority (EA), which becomes a condition of the mining tenure. As a matter of policy, DNRM needs to insert conditions in the associated lease that require:

1. Every application for an EA includes a Mine Closure Plan that conforms to the DEHP guidelines.
2. No application can be approved if its Mine Closure Plan is not formally approved by DEHP.
3. The approved Mine Closure Plan for an approved mining operation must be periodically reviewed and submitted to DEHP for consideration and re-approval.

If this approach is not practicable, a legislative approach will be required.

DEHP needs to create a set of 'Guidelines for Preparing Mine Closure Plans'. The guidelines created by the Western Australian Department of Mines and Petroleum and Environmental Protection Authority appear to be the best Australian guidelines currently available and (along with the best international closure guidelines) should be used as prime sources for development of Queensland guidelines. The Western Australian model includes a three-yearly review (DMPEPA, 2015) and this appears reasonable. Every review should require genuine DEHP involvement prior to submission to avoid a procedural 'tick-and-flick' mentality by DEHP.

There are many advantages to this reform:

1. It is a desirable whole-of-government approach, bringing together the views of DEHP, DNRM, State Development and Treasury.
2. It makes the future (and the obligations to fund and manage that future) real.
3. It provides, up front, for all parties, details of the procedures that *must* be followed, the fully-costed rehabilitation works that *must* be completed, the funding that *must* be in place to carry out the closure plan.
4. If the works are fully and accurately costed with matching financial assurances, there is an incentive for careful cost management, good design and planning and effective rehabilitation.
5. These procedures, rehabilitation works and costing/funding calculations must be signed off by DEHP for approval to be granted, because DEHP will be held accountable for the quality and completeness of rehabilitation – and the consequences of rehabilitation failures and inadequacies.
6. The three-yearly review system means that mine management and the government oversight authority (DEHP) are always aware of the details of their responsibilities.
7. It places the closure process as part of the continuum of mine planning and design. Final rehabilitation works at closure are seen as just the last stage of an integrated progressive rehabilitation process.

Because the mine closure plan is a condition of tenure, in the pre-approval stage, it provides the opportunity for true community consultation, regarding the closure process – future land uses, community involvement in the rehabilitation works (staged and final), etc. This is critical to good closure planning, but is present now, only with the goodwill of the development applicant. Indeed, true community consultation on all stages of the life of the mine needs to be mandatory.

HAVE DEHP REGULATE THE ENVIRONMENTAL PERFORMANCE OF ALL SITES

Currently, DEHP regulates the environmental performance of active (operator-controlled) mines and oversees any rehabilitation of these sites and DNRM monitors and physically remediates abandoned mines. This is an improvement over the previous system, where the mining-oriented departments that regulated the environmental performance of mining operations were notoriously subject to regulatory capture (Hutton, 2013). DEHP thus has a regulatory environmental role on operator-controlled sites (but not on abandoned sites), while DNRM manages all issues confronting abandoned sites.

It was wise to remove a mining-oriented department from regulating the environmental performance of mine operators, but the solution is flawed. The rehabilitation problems of operator-controlled sites and those of abandoned sites are much the same. Yet they are treated as if they are completely separate issues to be managed by two different agencies. The two departments have very different mind-sets and expertise. DEHP, responsible for environmental protection, has a prime focus on environmental restoration. DNRM, responsible for facilitating mining and regulating mine safety, has a prime focus on public safety issues (such as ground subsidence and uncapped shafts).

This artificial division of responsibility inevitably creates compartmentalised thinking. For DEHP, there is the risk that regulators of operator-controlled sites may fail to properly appreciate the cause-and-effect links between current practices and future liabilities and legacy risks. Regulators would benefit from being exposed to the problems of abandoned sites to learn about legacy risks. They would then have first-hand experience of what can go wrong, because at legacy sites there is failure on multiple fronts - safety, environmental, economic and social. For DNRM, there is the problem of being required to perform the physical environmental rehabilitation of abandoned sites without advice or assistance from the department that holds the most scientific knowledge in this field.

The rehabilitation of both operator-controlled sites and abandoned sites would thus be improved if a team within DEHP regulated the environmental performance on all sites (active, 'care and maintenance', closed and abandoned) and used any relevant regulatory powers that it had to maximise the effectiveness of all site rehabilitation.

This may help to resolve a difficulty revealed in the 2013-14 QAO report – that a lack of protocols between DEHP and DNRM about the management of 'care and maintenance' sites had resulted in sites remaining in care and maintenance while the departments disputed over the administrative and regulatory responsibility (QAO, 2013-14).

If we assume that DNRM retains responsibility for abandoned sites, this proposed change needs to be managed with sensitivity. There must be no perception of one department being ordered about by the other in some destructive master-servant relationship. It is incumbent on DEHP regulatory staff and DNRM implementation staff to *cooperate* on the prioritisation and management of abandoned sites. The environmental expertise of DEHP will complement the mine safety expertise of DNRM to improve the management of abandoned sites. This scenario does not imply that DEHP is to be involved in the physical rehabilitation of abandoned sites – just that it perform a (tactful) oversight role and provide valuable environmental advice and consultation, where appropriate.

HAVE A MULTIDISCIPLINARY BODY REHABILITATE ABANDONED SITES

It is much preferable to have one body to regulate the environmental performance of all sites (operator-controlled and abandoned) and a second body to perform the physical rehabilitation of abandoned sites. However, it would benefit both bodies, if each temporarily seconded staff to the other, for those staff to gain a wider perspective and broader work experience.

The management of abandoned sites is presently carried out by DNRM under the Abandoned Mine Lands Program (AMLP). This work could continue under DEHP regulatory oversight, as previously discussed. Indeed, one can argue that the laxities of DNRM's predecessors (such as Mines Department and DME) were largely responsible for the problems of abandoned sites and so DNRM has a continuing duty to rectify past failures. However, there is the potential for destructive inter-departmental friction.

A second option would be to move the management responsibility to DEHP to avoid potential friction.

However, this does not solve the problem of compartmentalised thinking. Presently, DEHP environmental expertise and thinking are excluded from the management of abandoned sites – now DNRM geological and mining expertise and thinking would be excluded. DNRM staff could be transferred to DEHP to supply this expertise, but this runs the risk of the ex-mining staff being regarded with suspicion in an environmental department and consequently being sidelined and having their career paths blighted.

A third option would be to adopt a variation of Recommendation 13 of the 2007 SDPC report, which recommended, in part, that the Directors-General of DME (now DNRM) and EPA (now DEHP) and Treasury immediately establish a senior executive level inter-departmental management committee to manage the inclusion of new sites in the abandoned mines program, and ensure that the technical advice and expertise of EPA and DME be applied to managing complex abandoned mine sites. (SDPC, 2007). Admittedly, this recommendation is misleading. The EPA (DEHP) participation on the committee was apparently only to ensure that the regulator pursued all legal avenues to force the miner to rehabilitate. However, such a committee might be able to promote a coordinated approach to the management of abandoned sites.

However, the best solution would be to transfer the management of abandoned sites to an independent corporate body whose only function was the effective (and cost-effective) rehabilitation of mine sites under a charter of responsibilities that included the maximum cost-effective involvement of local communities in the work. This would add social and economic benefits to the environmental benefits of the rehabilitation work. Staff from both DEHP and DNRM would be temporarily seconded to this body to add the richness of their expertise and world-view to the diversity of talent.

Whatever path is followed, there needs to be a more open attitude, regarding rehabilitation operations, with public reporting of the situation, the policy being followed, and the progress made in dealing with individual sites.

MAKE GOVERNMENT RESPONSIBLE FOR THE REHABILITATION OF ALL ABANDONED SITES

Recommendation 12 of the 2007 SDPC report recommended that DME (now DNRM) be made immediately responsible for the rehabilitation of all abandoned mines (SDPC, 2007). It argued that because the State authorised access to the resources, the State was responsible for any ongoing liability due to inadequate rehabilitation of the site (SDPC, 2007). While this argument made for state responsibility for all abandoned mines does indeed apply to all abandoned mines, the recommendation itself is misleading. A close reading indicates that 'all' refers to mines abandoned both before and after 1 January 2001, when the environmental regulation of the mining industry was transferred to the EPA. The report never defined what it meant by the term 'abandoned mine', but it appears as if it meant an abandoned mine that should be in the AMLP, which was and is limited to abandoned mines on state land. It also appeared to regard the management of abandoned mines to be primarily non-environmental, specifically referring to mine capping.

However, the 2012 QFCE report interpreted the 2007 SDPC report as indeed meaning all abandoned sites, accepted that the reasoning does apply to all abandoned sites and reasoned that the government had not adopted Recommendation 12 of the 2007 report because it considered abandoned mines on private land to be the responsibility of the landholder. It then concluded that one agency having responsibility for all abandoned mines might assist both in identifying which mines might cause harm and in responding to that possibility. It further concluded that imposing responsibility for abandoned mines on private landholders might deter them from reporting environmental harm that might be occurring. It regarded abandoned mines as a primarily environmental problem and went on to recommend in Recommendation 13.17 that the Queensland government should determine which of its agencies should be made responsible for all abandoned mines (QFCE, 2012). This recommendation implied that the government was (or should be) responsible for *all* abandoned mines – the question was merely which agency should administer the responsibility. Recommendation 13.17 was not adopted.

The government's continuing rejection of responsibility for the rehabilitation of legacy sites on private land has not been challenged and local authorities seem unaware of the consequences – that the government has, in effect, transferred responsibility for ameliorating the consequences to landholders and local authorities. Any future legal disputes regarding responsibility or liability would serve no societal benefit. It is time for the government to accept responsibility for these sites. A landowner may have

received some form of payment from the mining operator for damage caused to the landowner's land, if the operation was relatively recent. However, such payments are not for the satisfactory rehabilitation of the site – that is a governmental and operator responsibility. Landowners also lack the sophisticated engineering capacity to deal with such problems. Funding for this long-overdue reform is addressed later in this paper.

IMPROVE FUNDING

RAISE MORE FUNDS FOR THE REHABILITATION OF ABANDONED SITES

The Queensland government presently funds the rehabilitation of abandoned sites from an annual budget allocation – there is no direct contribution from the resources industry (such as a levy). Present funding is already manifestly inadequate. If the government accepts its responsibility for the eventual rehabilitation of all abandoned mines, significant additional funding will become even more critical.

The state could discipline itself by allocating a fixed percentage of royalties received from the resources sector to the task of rehabilitating legacy sites. This is logical – if the state is gaining financial benefits from present resource operations, then it should be allocating some of those funds to rectify the deleterious environmental consequences of past failures in regulating the sector. Mining, petroleum and LNG royalties amount to over two billion dollars per year (State of Queensland Treasury, 2015). A 1% allocation would translate to only $20 million per year to tackle a billion-dollar-plus problem, but it would still be more than double the 2016-17 budget allocation.

The state could impose an annual levy (say 1%) for legacy site rehabilitation on Financial Assurances lodged for new resource operations. The Northern Territory and Western Australia already impose a 1% annual levy on new mines. However, the Western Australian scheme loses more in refunded bonds than it gains in annual levy income (Pepper, Roche and Mudd, 2014). The Northern Territory scheme compensates resource operators by applying a 10% discount to the rehabilitation security bond. However, this bond includes a 15% security component on top of the 100% security and the effective security percentage is still a minimum of 100% (Department of Mines and Energy - Northern Territory, 2015). Any Queensland annual rehabilitation levy without any compensation to the resources sector would be fiercely resisted by the sector.

ELIMINATE THE DISCOUNTS ON FINANCIAL ASSURANCE PAYMENTS

In Queensland, an operator that holds an EA for a mining or petroleum lease must pay a financial assurance to the administering authority to cover the operator's estimated cost for site rehabilitation works. However, operators can apply for three discounts (totalling 30% of payments). The total rehabilitation liability is calculated by subtracting the proposed discount amount from the 100% rehabilitation liability amount. Therefore, even assuming that an operator's calculated cost was not an under-estimate, the taxpayer could still be saddled with up to 30% of the final rehabilitation cost.

The Financial Discount is available is available for every EA holder that submits certified documentation to demonstrate sound financial health and a declaration that the costs of rehabilitation have been adequately budgeted for.

The Progressive Rehabilitation and Certification Discount is available for every EA holder which avoids impacting areas of remnant vegetation or where areas of significant disturbance are being proactively rehabilitated.

The Waste Management Discount is available for every EA holder that can demonstrate it is not undertaking significant high risk storage activities (waste rock dumps, tailings storage facilities, regulated dams, brine and landfill waste), or has implemented measures that reduce the amount of waste that would otherwise be stored in on-site high risk storage activities (QG, 2015c).

The Financial Discount makes no sense and needs to be ended. Every company seeking an EA should be required to demonstrate sound financial health and provide detailed evidence (not a mere declaration) that the costs of rehabilitation have been adequately budgeted for, to gain approval for any proposed development, in the first place.

The Progressive Rehabilitation and Certification Discount makes more sense as it rewards better environmental behaviour, but should still be eliminated. Companies should be required to provide details of how they will minimise impacts on areas of remnant vegetation and they should be required to provide a progressive (legally

enforceable) rehabilitation plan, to gain approval for any proposed development. If companies refuse to conform to these societal norms, approval must be denied. It is important that site operators progressively rehabilitate the site during operations. The discounted cash flow method (NPV) encourages the deferral of expenditure and so works against progressive rehabilitation, but this should not be allowed. Deferred rehabilitation work may never be performed - the operator may just walk away, when the rehabilitation costs greatly exceed the financial assurance. For example, one site has been in 'care and maintenance' since 1998. The financial assurance held for this site is $3.8 million while the rehabilitation costs are estimated as $14.2 million (QAO, 2013-14).

The Waste Management Discount should be eliminated – the way that this discount is phrased, every EA holder would automatically receive it, because all that the EA holder needs to do is to demonstrate that measures will be implemented to 'reduce the amount of waste that would otherwise be stored in on-site high risk storage activities'. A calculated reduction of 0.01% would qualify.

These discounts are contrary to Recommendation 8 of the 2013-14 QAO report, which recommends that DEHP *ensure* that the financial assurance that it calculates and collects reflects the estimated cost of environmental rehabilitation. The Financial Assurance collected (before discounts) is supposed to cover the operator's estimated cost for site rehabilitation works. There is already ample evidence, quoted in the QAO report, that past estimates were often grossly inadequate. There is no contingency fee, as in the Northern Territory system. Yet, in Queensland, operators can obtain up to a 30% discount.

Ending these unnecessary discounts cannot be made retrospective, but they must not apply to future applications – they are nothing but a state subsidy of the depletion of non-renewable state resources.

END THE OFFLOADING OF LARGE REHABILITATION LIABILITIES TO MINNOW COMPANIES

The following sequence of events is now coming to public attention (particularly for large coal mines with large rehabilitation liabilities and a product in perceived structural decline):

1. While prices and grades are high (and consequently cash flows are highly positive), no site rehabilitation is carried out and no site rehabilitation plan is prepared.
2. As the grades and prices and cash flows decline, the operator announces plans to close the site and the government-of-the-day expresses its confidence in the site's rehabilitation.
3. The operator releases a reassuring statement that it recognises the importance of rehabilitation at the site and will work with the government to finalise the rehabilitation plan, while the government-of-the-day assures the public that it is working closely with the operator to ensure that rehabilitation of the site is satisfactorily completed;
4. Prior to any of the promised rehabilitation taking place, the operator sells the operation and its unfulfilled rehabilitation obligations for $1 to a small corporation with negligible assets.
5. The original operator releases a reassuring statement that it will make a contribution (unquantified) towards the so-far unfulfilled site rehabilitation obligations.
6. The new owner on-sells the operation to another corporation, even more obscure with even less financial credibility.
7. There is no more talk of the original operator contributing to the task of site rehabilitation.

For the long-term good of the mining industry, this has to stop – now. The media has been publishing this sequence of events – Steps 1 and 2 (Latimer, 2012), Step 3 (Schwarten, 2012), Steps 4 and 5 (Tasker, 2013), Steps 6 and 7 (Shift Miner, 2015). Whatever the true motives of the large operator, the public perception can only be that another large corporation is seeking to evade its rehabilitation obligations. Public condemnation and distrust of the entire mining industry will surely follow when the final step is first taken – that of the last owner's disappearance into pre-planned bankruptcy, with no recoverable financial assets and government left with a financially-ruinous rehabilitation burden.

There appear to be only two legislative ways to end this practice – either the practice has to be legally treated as grand fraud and the perpetrators liable for personal criminal prosecution, or any corporation involved in the practice must face truly brutal financial penalties.

A non-confrontational approach would be for the resources sector to publicly recognise that this practice is a gross violation of its own 'social licence to operate' and to have their peak bodies publicly repudiate any corporation indulging in this practice.

Should this fail to eventuate, government could create a Public Register of 'Corporations Acting against the Public Good', with links to the reasons why these corporations are on this register. The corporations on the register would be denied approval for any future development application until they take such action as would warrant their removal from the register. If a corporation on the register were to be acquired by another corporation, that corporation would go on the register.

END THE PRACTICE OF TRANSFER PRICING MANIPULATION

Transfer pricing occurs when two companies that are part of the same multinational group trade with each other and the parties establish a price for the transaction. This is entirely lawful, but a group with an overseas stock market listing may *artificially* distort this price to minimise their payments to Australian governments by recording as much of its profit as possible in a tax haven with low or zero taxes. This is known as transfer pricing manipulation and is illegal – if it is proven. Even in the 1970s, this practice was used by multinational groups to minimise, even eliminate, the tax owed to the Australian Government.

The practice continues today for the same purpose and the Australian Government is currently in legal dispute with major multinational groups, regarding the channelling billions of dollars in profits from iron ore sales through subsidiary overseas companies that pay little tax (Chenoweth, 2015a). In the mining sector, the practice currently is known as the Singapore Sling, because of the marketing hubs set up by mining multi-nationals in Singapore to facilitate transfer pricing transactions.

The same transfer pricing manipulation is also used to minimise royalty payments, where royalties are based on the price received for the first sale. If the first sale is to another company in the group, rather than a buyer truly independent of the seller, the price can be manipulated to minimise royalty payments to state and territory governments. The Queensland government is currently involved in major royalty disputes with multinationals over transfer pricing practices (Chenoweth, 2015b; Ludlow, 2016).

Multiple legal disputes in multiple jurisdictions are evidence that state and territory governments and the Australian government need to work together to tighten legislation to make transfer pricing manipulation more easily legally proven and the perpetrators more easily prosecuted and ultimately to make it financially pointless (i.e. transfer pricing manipulation does not result in reduced payments to government).

A first step would be for the Queensland Office of State Revenues (which collects mining and petroleum royalties) to liaise with its counterparts in the other states to optimise the legal effectiveness of their royalty-gathering legislation. For example, is the Western Australian legislation indeed much tighter in levying royalties on the price to the end seller than the Queensland legislation, as has been claimed (Chenoweth, 2015b)? Should there be a universal return to a royalty system of imposing flat rates per unit of resource extracted?

END THE PAYMENT OF ROYALTIES TO NON-STATE ENTITIES

On some blocks of land titled before 1910, the ownership of the coal beneath the land surface was granted to the landholder and not retained by the government. A resource company can acquire this land and effectively pay the royalties to itself.

The future loss of royalties over the working life of a single large open-cut mine may total hundreds of millions of dollars – and there is more than one such mine. It has been estimated that in the ten years up to the end of 2009, the state missed out on $554 million in royalties paid to private owners. The Queensland government has no plans to review the relevant legislation. One economist called for the removal of the anomaly, because (it was argued) the state still legally owned the resources. However, a property lawyer who has represented landholders with these title deeds said it would be very complex as it would require changing the *Acquisition of Land Act 1967* and working out new methodology for compensation (McBryde, 2015).

The government may feel that any unquantifiable financial benefit resulting from removing this anomaly (of limited applicability) in the present situation of declining coal prices and consequent falling coal royalties is not worth the political cost of alienating the entire mining sector. Alternatively, it can be argued that the need for governments

to maximise what royalties it can receive is now more important than ever. The question is one for government to resolve, but government should address the question and publicly justify whatever position it decides to take.

RECOMMENDATIONS

If implemented, the following recommendations will significantly improve the effectiveness of site rehabilitation in Queensland:

1. Determine the fates of all rehabilitation recommendations made in past major government reports, analyse those not fully implemented, recommend which of these deserve renewed scrutiny and publicly release the resulting report.
2. Mandate staged rehabilitation for all sites still the responsibility of their operators.
3. Require the granting of any EA be conditional upon the inclusion of a site closure plan that conforms to associated closure guidelines and is acceptable to DEHP.
4. Have DEHP regulate the environmental performance on *all* sites (active, 'care and maintenance', recently closed and abandoned) and use any relevant regulatory powers that it has to maximise the magnitude and quality of any rehabilitation.
5. Create a single multi-disciplinary body to undertake the physical rehabilitation of all abandoned sites.
6. Have the state government take responsibility for the rehabilitation of abandoned sites on private land.
7. Eliminate the three discounts on the financial assurance payments made by operators to government.
8. End the practice of companies selling large coal assets (and the attendant large unfunded rehabilitation liabilities) for effectively nothing to minnow companies which have no prospect of ever funding the required site rehabilitation.
9. Have the Queensland Office of State Revenues liaise with its counterparts in the other states and the Northern Territory to optimise the legal effectiveness of royalty-gathering legislation.
10. If practicable, remove the anomaly where some mine operators pay royalties to private landholders (often one of their own subsidiaries) instead of to the state.

LIST OF ABBREVIATIONS

AMLP Abandoned Mines Land Program (Queensland)
CMLR Centre for Mined Land Rehabilitation (University of Queensland)
CSG Coal Seam Gas
DEHP Department of Environment and Heritage (Queensland)
DME Department of Mines and Energy (Queensland)
DNRM Department of Natural Resources and Mines (Queensland)
EA Environmental Authority
EPA Environmental Protection Agency (Queensland)
QAO Queensland Audit Office
QFCE Queensland Floods Commission of Enquiry
SDPC Service Delivery and Performance Commission (Queensland)
DMPEPA Department of Mines and Petroleum & Environmental Protection Authority (Western Australia) – used only in citations
QG Queensland Government - used only in citations

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AUTHOR PROFILE

The author began his career as a milling metallurgist with Mount Isa Mines at Mount Isa, before returning to the University of Queensland to complete his M.Sc. He then worked on Hamersley Iron's financial modelling system, before returning to Brisbane to work for MIM Holdings as a Technical Computer Analyst. He later worked in the Queensland Public Service, holding the position of Principal Research Adviser at his retirement. He has lately involved himself in investigating the benefits to be derived from the involvement of communities and professional organisations in what he regards as the increasingly important issue of site rehabilitation.

FRASER ISLAND LAKES: A REVIEW OF WATER QUALITY

MOSS, A.

This paper undertakes a review of available water quality data for dune lakes on Fraser Island. The data include both historic literature data and more recent data from work undertaken by the Queensland Department of Science, Information Technology and Innovation. The main aims of the paper are firstly to establish a baseline of water quality for future reference, secondly to assess whether there is any evidence of change over time and thirdly to assess if any changes detected are likely to have been due to the high level of tourist visitation. Tourist pressure is a significant issue, with visitation to Lake McKenzie of the order of 1000+ persons every day, although visitation to other lakes is much lower.

The compiled data from different sources varied in spatial and temporal extent and range of indicators. Nevertheless, it was found that there was a sufficient degree of consistency to propose that the data set was suitable as a baseline against which future monitoring data can be compared. The data were too limited to allow robust statistical assessment of trends but subjective assessment indicated no evidence of trends over the period covered, which extended from 1964 to present for some indicators and from 1989 for others. The apparent absence of trends indicates that to date, tourist visitation impacts have been limited. However, it is suggested that this is not a justification for complacency and that some ongoing assessment of the health of these lakes, particularly Lake McKenzie, should be instituted with the aim of ensuring that any incremental deterioration is detected before it becomes irreversible. Additionally, a more comprehensive monitoring of the rates of visitation both to the island and to individual lakes should be established.

Queensland Department of Science, Information Technology and Innovation
Ecosciences Building, 41, Boggo Rd, Dutton Park, Brisbane 4102

INTRODUCTION

Fraser Island is one of Australia's iconic World Heritage areas, having been listed in 1992. Prior to that time, the island had mixed land use including national park, forestry, sand mining and a few small townships. Of these, the only intensive land use was sand mining and this was confined to a strip along the east coast, south of Dili village (Sweett 2008). Its footprint is now visible as an area of non-remnant vegetation in the regional ecosystem mapping of the Queensland Herbarium (Queensland Government 2016). Following World Heritage declaration, anthropogenic land use largely ceased, with the exception of a few small township and resort areas. Today, nearly all the island is in a near natural vegetated condition.

Fraser Island is the largest sand island in the world. Over the past two million years, ocean currents and waves have swept sand north from the continental shelf of New South Wales and southern Queensland. Sand accumulated and now covers the ancient bedrock to form dunes parallel to the coast, leaving only peaks uncovered—today's headlands, Indian Head and Waddy Point. Over hundreds of thousands of years, strong onshore winds have blown loose sand inland into high dunes, which spread to engulf everything in their paths and form a sequence of overlapping dunes Over time the dunes have mostly become vegetated and, in the hollows between the dunes, freshwater lakes have formed. There are over 100 dune lakes, of varying types, on Fraser Island. (Fraser Island Defenders Organisation, 2016; Queensland Parks & Wildlife Service, 2016).

Both the immediate surrounds and the catchments of these lakes are largely undisturbed, none of them being situated in old sand mining areas. However, the ever increasing numbers of tourists visiting and swimming in some of these lakes has resulted in concern about impacts on their water quality and other ecosystem attributes (Arthington *et al.* 1990, Hadwen 2003, Hadwen *et al.* 2005). There is no comprehensive recording of total visitor numbers to the island, but from available information it is estimated that there were well over 360,000 visitors to the island in 2015, with numbers on the increase. Thus, there is clearly a basis for concerns about water quality. Furthermore, many of the lakes are highly oligotrophic, and therefore particularly sensitive to the impacts of high levels of visitation.

Partly as a result of these concerns, over the past 50 years there have been a number of surveys of water quality in the more popular lakes. These are only a small fraction of the total number of lakes but have included most of the larger and all the recreationally important ones. The timing and extent of these surveys has been dictated by available funding or by individual research projects, and so they have been both sporadic and varied in scope (Bayly 1964, Arthington *et al.* 1990, Hadwen 2002, 2003). During 2012-13, the Queensland Department of Science, Information Technology and Innovation (DSITI) collected significant additional data in a wide range of lakes. Overall, a substantial amount of data has been collected and, despite its fragmented nature, it presents a reasonably consistent assessment of the quality of waters in these lakes. The aims of this paper are to present the available data (some of which is in difficult to access reports) and to use it to characterise water quality of these lakes, to assess whether there is any evidence of change over the period of record and to comment on the issue of tourism impacts. Water quality data for two lakes on North Stradbroke Island is also included here (DSITI data, 1996-2002). These lakes lie in similar dune settings to those on Fraser Island and the data are therefore relevant for comparison with the Fraser Island lakes.

OVERVIEW OF DUNE LAKES

Timms (1982) describes six lake types found in coastal sand dunes. Of these, type (i) waterbodies perched in leached dunes (perched lakes) and type (iii) water table window lakes predominate on Fraser Island, with perched lakes in the great majority. A brief description of these lakes, based on Timms (1982) and Arthington *et al.* (1990) is provided below. FIG. 1 provides a conceptual overview.

Sand islands like Fraser or North Stradbroke have a principal or regional aquifer that can be described as an elongated mound running parallel to the island's long axis (Leach 2011). Where dune depressions intersect this water table, a window lake is formed. These window lakes occur mainly around the island margins because increasing elevation inland means that dune depressions are not deep enough to intersect the regional aquifer. For example, the peak elevation of the regional aquifer on North Stradbroke Island above mean sea level varies between 34m and 44m (Leach 2011).

As their name suggests, perched lakes sit in dune depressions that lie above the regional aquifer. In the early stages of their formation, rain falling into these depressions simply permeates down to the regional aquifer. However, through various processes, principally the formation of a sub-surface indurated sand layer (Cox *et al.* 2011), organic matter acts to create an increasingly impervious layer in the depression. Eventually, rainfall starts to exceed the rate at which water permeates down to the regional aquifer and a lake forms, along with a surrounding localised perched aquifer. Not much is known about the precise nature and extent of perched aquifers on Fraser Island, but those on North Stradbroke Island are stated to be complex (Cox *et al.* 2011).

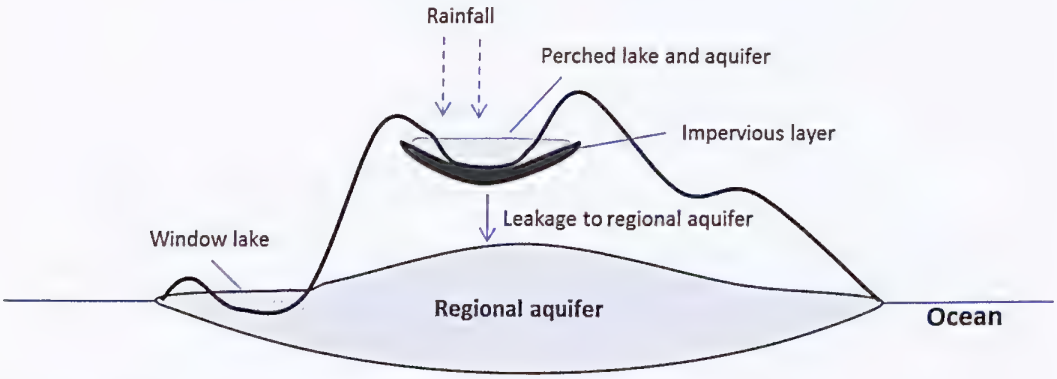

FIG. 1. Conceptual overview of window and perched lakes on a dune island.

TABLE 1. Study lake dimensions and estimated visitor rates.

	Area (Ha)[a]	Max depth (m)[b]	Average daily visitation[c]	% visitors swimming[c]
Perched lakes				
Allom	8	5	50-100	20
Basin	4	8	50-100	50
Benaroon	51	4	<20	50
Birrabeen	117	7	120	70
Boomanjin	239	9	<20	10
Bowarrady	101	6	<2	0
Garawongera	51	5.5	50	60
Jennings	18	4	<2	0
McKenzie	84	9	>1000	90
White	114	2	<2	0
Brown (Stradbroke)	30	5	nd	nd
Window Lakes				
Ocean	34	2	50	50
Wabby	3	8	100	90
Blue (Stradbroke)	9	8	nd	nd
a – Area based on Google Earth lake outlines				
b – Max depth estimated from DSITI field surveys or from Bayly (1964)				
c – Based on estimates from Queensland Parks and Wildlife Service				
nd – no data				

The ongoing balance between water gain and loss is reflected today in temporal variations in the levels of perched lakes on Fraser Island. During dry weather, evaporation and slow leakage down to the regional aquifer reduce lake levels while heavy rainfall raises them again, with variations up to 4m (Arthington *et al.* 1990). On North Stradbroke Island, some dune lakes completely dry out during drought periods (Cox *et al.* 2011). Fluctuations in levels are anticipated to increase as a result of climate change (Hadwen & Arthington 2011), with potential impacts on fringing aquatic vegetation and associated biota.

These hydrological processes indicate that perched lakes experience long water residence times. Typical maximum lake depths (Table 1) are in the range of 5-9m. DSITI water quality surveys at sites around Lake McKenzie have shown that a 9m depth persists across a large portion of the lake. As there are no defined inflows or outflows, a reduction in level of 4m would only account for about 50% of the lake volume. Reductions of this magnitude would only occur over many months of dry weather. This suggests that water residence times would be of the order of years rather than months. Long residence times in any water body act to increase vulnerability to pollutants.

Much shorter residence times occur in some window lakes. Blue Lake on North Stradbroke Island has a formed outflow and receives significant inflows from the regional aquifer. Average residence times in this lake have been calculated at 29 days (Marshall & McGregor 2011). Window lakes on Fraser such as Lake Wabby, with no formed outflow, are likely to have significantly longer residence times (Barr *et al.* 2013) although no quantitative estimates are available. However, given their connection to the large regional aquifer, with its constant outflow to the ocean, these are still likely to be shorter than residence times in perched lakes.

The great majority of lakes on Fraser Island are of the perched variety, located inland. There are only a few recognised window lakes, including Lake Wabby and Ocean Lake, both situated close to the eastern shore and Yankee Jack Lake near the western shore (Arthington 1990). Lake Wabby has some characteristics of a dune barrage lake but it has no defined inflow and is functionally a water table window (Arthington 1986).

DESCRIPTION OF STUDY LAKES

Water quality data from a total of 12 Fraser Island lakes are included in this paper together with data from two lakes on North Stradbroke Island for comparison. The lakes are listed in Table 1, including dimensions and estimated visitation rates. Lake areas are approximate only, being dependent on the precise delineation of lake boundaries, but they provide a reliable measure of relative magnitude. Lake locations on Fraser Island are shown in FIG. 2.

There have been no quantified assessments of visitation rates to individual lakes since some limited information collected in 1990 (Arthington 1990), and so the current rates (Table 1) were estimated based on the expert opinion of Queensland Parks and Wildlife rangers working on the island (Clifton pers comm). While these are necessarily qualitative, they are up to date and provide a reasonable estimate of the relative magnitude of visitation to each lake, including swimming rates, the activity most likely to impact on water quality. (Toilet facilities are always located well away from the lakes and are a very low risk to water quality). Also available are automated vehicle counts at various sites on the island. A total of around 111,000 vehicles were recorded visiting Lake McKenzie in 2015. Assuming an average of 3-4 persons per vehicle (some vehicles are 4WD tour buses), this equates to an average of more than 1000 persons visiting the lake every day. What these data clearly indicate is that visitation to Lake McKenzie is not only extremely high, but is more than half an order of magnitude greater than visitation to the next most popular lake, Lake Birrabeen. Visitation to all the other lakes is lower again, with some lakes having virtually nil visitation. Thus, if there are visitation impacts on water quality, Lake McKenzie is, by a large margin, the lake most at risk.

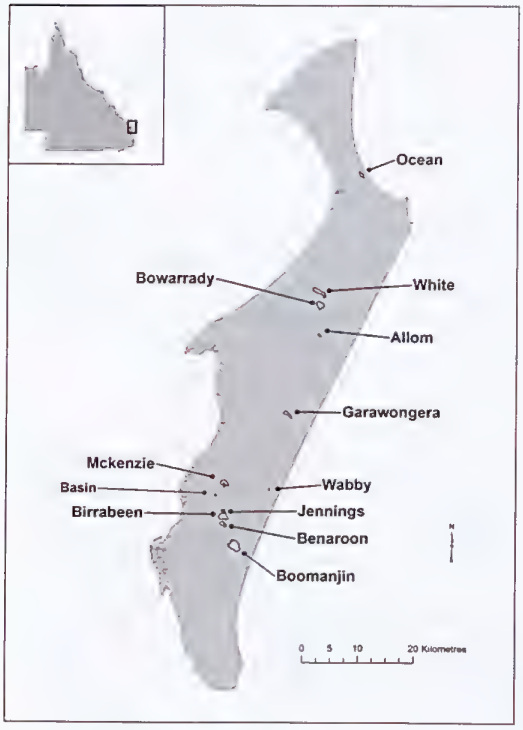

FIG. 2. Locations of Fraser Island lakes.

METHODS

This paper presents data from a range of literature sources and data collected more recently by DSITI.

LITERATURE DATA SOURCES

- Bayly (1964) – a single set of samples collected in October 1963 – field readings and major ions
- Arthington *et al.* (1990) – Nine sets of samples collected by the Queensland Environmental Protection Agency water science group (now DSITI) approximately monthly from July 1989 to May 1990. Field readings (temperature, pH, conductivity, dissolved oxygen, secchi depth), major ions, nutrients (total phosphorus only) and chlorophyll a
- Hadwen (2002), Hadwen *et al.* (2003). Data collected in 1999 and 2000. Field readings, nutrients (nitrogen and phosphorus, total and soluble fractions) and chlorophyll a

DSITI MONITORING PROGRAMS

DSITI undertook monitoring in October, November and December 2012 in all the Fraser Island lakes in Table 1 except for Ocean Lake. In lakes Allom, Birrabeen, Boomanjin, Bowarrady and McKenzie, surveys were carried out by boat and included at least two or three separate sites. In lakes Basin, Benaroon,

TABLE 2. Range of sunscreen and insect repellent compounds tested and the sites monitored.

Sunscreen compounds	Insect repellent compounds	Lakes	No sites	Lake visitation rates
• Oxybenzone • Dioxybenzone • Sulisobenzone • Menthyl anthanilate • Ecamsule • Avobenzone • Homosalate • Octisalate • Octocrylene • Para amino benzoic acid (PABA) • Cinoxate • Octyl methoxy cinnamate	• N,N-Diethyl-3-toluamide (DEET) • Ethyl 3-[acetyl(butyl)amino] propanoate (IR3535) • Picaridine	McKenzie	5	Very High
		Birrabeen	2	High
		Allom	2	Moderate (limited swimming)
		Boomanjin	1	Very Low
Detection limits: Water: 100ng/L Sediment:150ng/kg				

Garawongera, Jennings, Wabby and White there were single edge sites only. In December 2013, single boat surveys were carried out in lakes Allom, Birrabeen, Boomanjin and McKenzie using the same sites as 2012. Data for each lake in the 2012-13 period are reported as averages or medians for all sites over all the surveys. Indicators sampled included field readings (temperature, conductivity, dissolved oxygen, pH), major ions, nutrients (total nitrogen, oxidised nitrogen, ammonia nitrogen, total phosphorus and filterable [0.45µm] reactive phosphorus) and chlorophyll a. Similar field readings and nutrient data were collected monthly by boat at two sites each in Brown Lake and Blue Lake on North Stradbroke Island between 1996 and 2002.

Monitoring for petroleum hydrocarbons comprised a one-off collection of water and sediment samples in two high use lakes (Birrabeen and McKenzie), a moderate use lake (Allom), a low use lake (Boomanjin) and a lake with nil vehicle visitation (Bowarrady) in December 2012.

Monitoring for sunscreen and insect repellents compounds in both water and sediment was undertaken in December 2013, a time of moderately high visitation and swimming rates. The aim was to assess the extent of general contamination throughout the lakes rather than the short-term presence of these contaminants immediately adjacent to large crowds of swimmers. Therefore, sites in Lake McKenzie were located throughout the lake, but included one site within 100m of the swimming area. Similarly, in most other lakes there was one site close to the swimming area and one well away from it. The scope of this sub-program is described in Table 2. Analytical methods for indicators monitored by DSITI are summarised in Table 3.

RESULTS

MAJOR IONS

Data for major ions from Bayly (1964), (Arthington *et al.* 1990) and DSITI data (2012-13) are shown in Table 4. The major ion data are based on single samples or the average of two samples. Perched lakes are all characterised by low ionic concentrations. Ionic proportions are consistent across lakes, being dominated by Na and Cl. They reflect the ionic proportions of the sea, indicating that atmospheric supply from the ocean is a major source (Bayly 1964). Similar ionic proportions occur in the two window lakes but concentrations are higher due to their greater proximity to the ocean (Bayly 1964). The data record for major ions covers a period of nearly 50 years and, while the data is limited, it indicates that ionic concentrations in all the lakes have remained stable, with no evidence of any long-term change in that period.

While proximity to the ocean can affect ionic concentrations, this generalisation can be affected by local factors. Blue Lake, a window lake on North Stradbroke Island at a similar distance from the ocean to Lake Wabby, has ionic concentrations (based on conductivity measurements) similar to inland Fraser Island lakes. In this case, the reason is likely to be the more rapid water turnover times (averaged at 29 days [Marshall & McGregor 2011]) compared to Lake Wabby.

TABLE 3. Analytical methods for DSITI monitoring programs.

Indicator	Method	Limit of Resolution
Cations	APHA AWWA 2005, Method 3120 B	Na: 1mg/L Ca, Mg, K: 0.1mg/L
Chloride	APHA AWWA 2005, Method 4110 B	0.1mg/L
Alkalinity	Potentiometric auto titration	2mg/L
Bicarbonate	By calculation	2mg/L
Temperature	YSI 6600 multi-parameter probe. Conductivity & pH calibrated monthly. DO calibrated daily using Winkler titration	±0.5oC
Conductivity		±4µS/cm
pH		pH ±0.1
Dissolved oxygen (DO)		±2% saturation
Secchi Depth	Australian Standard 3550.7-1993	±5% of the reading
Optical density @385nm	4cm cell in GBC Cintra 10e spectrophotometer	
Nutrients preparation	Field filtration (0.45µm) for soluble fractions. Persulphate digestion for total N and P.	
Filterable reactive phosphorus	APHA AWWA 2005, Method – 4500-P G	2µg/L
Total phosphorus		3µg/L
Oxidised Nitrogen	APHA AWWA 2005, Method 4500-NO3 I	2µg/L
Total Nitrogen		10µg/L
Ammonia nitrogen	APHA AWWA 2005, Method 4500-NH3 H	2µg/L
Chlorophyll a	Lorenzen (1967)	0.5µg/L
Petroleum Hydrocarbons	The analysis method assesses three hydrocarbon fractions, based on the length of the carbon chain, C10 - C14, C15 – C28 and C29 – C36. Samples are filtered and acidified and then extracted using UCT universal extraction PAH/DRO 2000 mg / 83 mL cartridges. Analysis is by non-selective Flame Ionisation Detection. LOR: C10 - C14, C15 – C28 and C29 – C36 all 10µg/L.	10µg/L
Insect repellent and sunscreen compounds	The Organic UV filters and personal insecticide active ingredients listed were extracted from water and sediment samples using techniques outlined in Nieto et al. (2009) and Kaiser et al (2012). The extracted solutions were evaporated to dryness and redissolved in methanol suitable for HPLC/ UV analysis by a modified version of the method outlined in DIONEX application Note 223 (2009) and GC/MS analysis as outlined in Kaiser et al.(2012), WHO/667/2001 and WHO/IS/TC/668/2001.	Water: 100ng/L Sediment:150ng/kg

While data on the major ions is limited, more temporally extensive data are available for conductivity. These data show that short-term variations in ionic concentrations, associated with rainfall events, do occur. Examples from Lake McKenzie and Lake Wabby during 1989-90 (FIG. 3) show abrupt falls in conductivity between February and April 1990 following heavy rainfall (~600mm at the township of Eurong) in the intervening period. Clearly rainwater and local catchment run-off/ seepage has lower conductivity than ambient lake values. The typically higher ambient lake values are probably the result of evaporative effects and some atmospheric supply of salts. Evidence of the effects of evaporation was apparent in Lake Allom in December 2012 during a period of intense thermal stratification.

Conductivity in the epilimnion was 90µS/cm while in the hypolimnion it was in the range 71-74µS/cm, about 18µS/cm lower. The epilimnion was clearly shallow enough (<2m) for evaporative effects to become significant.

pH

Mean pH values from individual data sets are shown in Table 4. FIG. 4 shows pH mean and standard deviation values based on the combined data sets. Available data for the Fraser Island lakes vary from 4 values in Lake Garawongera to 47 in Lake McKenzie, so the extent of variation in some lakes is underestimated. However, both Boomanjin and McKenzie have >40 data points, so the variation in these lakes provides an indication of the likely extent of variation in other lakes. pH levels in the perched lakes, including Brown Lake on North Stradbroke Island, are nearly always below 5, with mean values in the range 3.9 to 4.8. Lake Garawongera appears to be an outlier, being a perched lake but with mean pH values almost one unit higher than most other lakes. pH values in the Fraser Island window lakes (Ocean and Wabby) are well above those of perched lakes, but this is not the case for Blue Lake on North Stradbroke Island.

pH values in individual lakes are variable, during 1989-90 pH in Lake McKenzie varied between 3.8 and 5.5. One suggested reason for this is that pH decreases due to ingress of humic acids from the catchment after prolonged rainfall (Arthington *et al.* 1990). However, Fraser Island perched lakes pH showed minimal response to large rain events. The rainfall between February and April 1990, which resulted in significant reductions in conductivity (FIG. 3), resulted in ≤0.1pH unit change in nearly all perched lakes. However there were marked decreases in pH in the window lakes in that period. This would suggest that while pH in perched lakes is in equilibrium with run-off and groundwater seepage, in window lakes this is not the case.

Variation in primary production is another potential cause of pH variability but there was no apparent relationship with chlorophyll a concentrations. Thus the cause of pH variability remains unclear although it is possible that measurement errors, due to the technical challenges of measuring pH in very low conductivity waters, are a factor. The pH data from Bayly (1964) was omitted from Table 4 altogether because it is completely inconsistent with all the other data, and almost certainly subject to significant errors. Despite the uncertainties around temporal variation and potential measurement errors, it can be stated that mean pH values in perched lakes would generally be expected to lie within the 3.9 to 5.0 range.

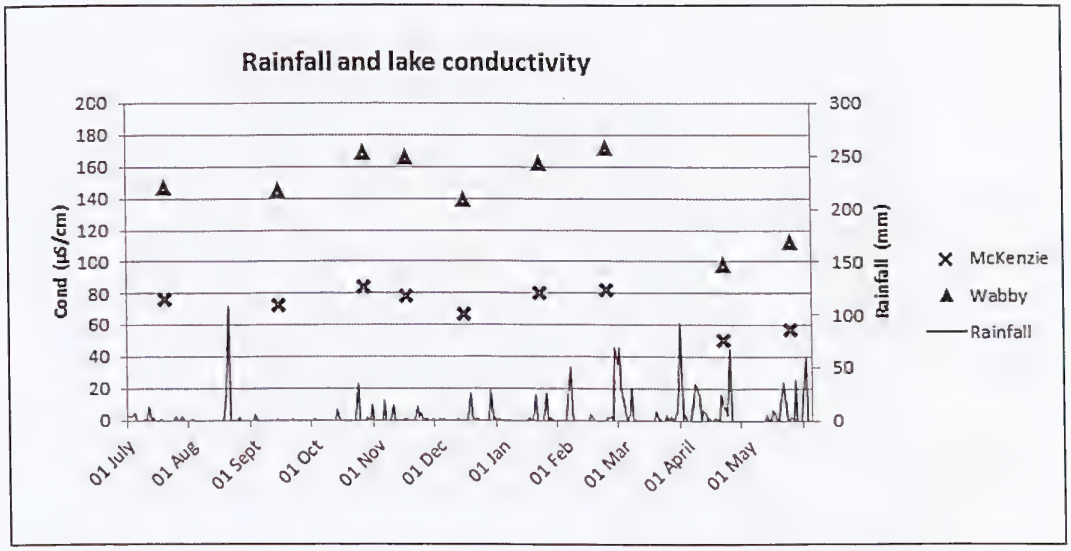

FIG. 3. Effects of heavy rainfall on conductivity in a perched lake (McKenzie) and a window lake (Wabby).

The low pH values in perched lakes are understood to be related to humic acids leached from catchment vegetation (Bayly 1964). The very low ionic concentrations in lake waters, particularly Ca, mean that there is little buffering capacity, so that only moderate amounts of humic acid would be sufficient to cause reduced pH. Alkalinity values are not shown in Table 4 but are mostly <3 mg/l, which is unsurprising given that the pH end point for alkalinity titrations is 4.6, similar to natural pH levels in most lakes.

The optical density of water samples from a range of lakes in October 2012 was compared with pH values, FIG. 5. The results were similar to those of Bayly (1964) in that there was a strong correlation between optical density and pH in perched lakes, with an r^2 value of 0.88, provided that Lake Garawongera data was omitted. While this is evidence of the influence of humic acids in regulating pH, Lake Garawongera is a significant outlier, having a pH well above what would be expected given its optical density. This

TABLE 4. Summary of available data for major ions, conductivity, pH and optical density in Fraser Island and North Stradbroke Island lakes.

Lake	Date	Na (mg/L)	K (mg/L)	Mg (mg/L)	Ca (mg/L)	Cl (mg/L)	HCO3 (mg/L)	Cond (µS/cm)	pH	Opt. Density @ 385 nm
FRASER										
Allom	1999							65	5.3	
	2012-13	10	0.8	1.1	0.5	18	3	85	4.5	0.62
Basin	1964	7.9	0.5	1	0.3	14.5	0.9			
	1999							64	5.0	
	2012-13	8	0.4	0.9	0.2	14	3	66	4.6	0.05
Benaroon	1964	9.8	0.5	1.1	0.4	17.8	0.5			
	1989-90	11	0.4	1.4	0.3	21.3		71	4.1	
	1999							84	4.6	
	2012-13	9	0.5	1	0.3	15	3	71	4.6	0.24
Birrabeen	1964	10.6	0.6	1.3	0.4	17.8	1.1			
	1989-90	11.6	0.4	1.3	0.3	22.3		70	4.3	
	1999							92	4.6	
	2012-13	11	0.5	1.2	0.2	19	3	84	4.6	0.09
Boomanjin	1964	11.8	0.5	1.3	0.4	20	nd			
	1989-90	15.0	0.5	1.7	0.4	25.2		87	4.1	
	1999							107	4.6	
	2012-13	11	0.5	1.2	0.5	20	3	84	4.3	0.77
Bowarrady	2012	12	0.5	1.4	0.2	21	3	98	4.6	0.25
Garawongera	1999							73	5.2	
	2012-13	10	0.6	1	0.5	17	6	73	5.5	0.23
Jennings	1964	9.5	0.4	0.9	0.4	15.1	nd			
	1989-90	10.4	0.4	1.2	0.2	19.8		71	3.9	
	1999							79	4.4	
	2012-13	10	0.6	1.1	0.5	18	4	93	4.3	0.79

Lake	Date	Na (mg/L)	K (mg/L)	Mg (mg/L)	Ca (mg/L)	Cl (mg/L)	HCO3 (mg/L)	Cond (µS/cm)	pH	Opt. Density @ 385 nm
FRASER (cont.)										
McKenzie	1964[a]	12.1	0.6	1.4	0.4	19	1.1			
	1989-90[b]	12.3	0.5	1.5	0.4	24.7		71	4.5	
	1999[c]							91	4.8	
	2012-13[d]	12	0.6	1.4	0.5	21	4	97	4.7	0.07
White	1999							102	4.7	
	2012-13	12	0.6	1.3	0.4	22	3	98	4.6	
Ocean (Window)	1989-90	43.8	1	4.8	0.9	71.3		213	5.7	
Wabby (Window)	1964	26.3	1.2	2.8	0.7	43.3	3			
	1989-90	28.3	1.1	2.8	0.8	48.5		146	5.6	
	2012-13	28	1.2	2.8	0.8	49	8	194	6	0.03
STRADBROKE										
Brown	1996-02							91	4.7	
Blue (Window)	1996-02							95	5.0	

a: Bayly (1964); b: Arthington (1990); c:Hadwen (2002); d:DSITI data 2012-13, nd – nil detected

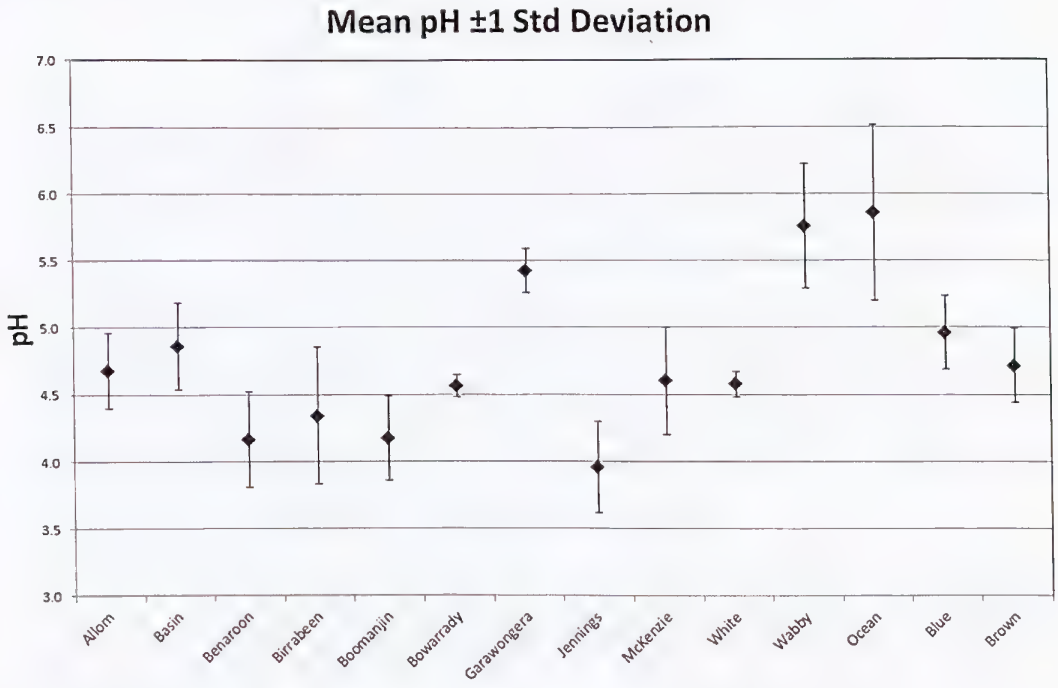

FIG.4. pH in lakes on Fraser Island and North Stradbroke Island – mean ±1 Std Deviation.

suggests that factors other than highly coloured humic acids have a role in moderating pH in this lake, although their identity is not known. Ionic concentrations in Garawongera were not dissimilar to other perched lakes.

Lake Wabby, a window lake, is included on FIG. 5 and is also an outlier. The higher values in this lake also indicate that factors additional to humic acids are affecting its pH climate. The pH levels in groundwater were not measured directly but DSITI has collected data from Eli Ck and other groundwater-fed creeks on the eastern side of the island. pH values in these were mostly in the range 5.0 to 5.3. This suggests that in-lake processes are affecting the pH of waters once they enter window lakes. In contrast, mean pH in Blue Lake, a window lake on North Stradbroke Island is 5.0, well below the values in Fraser Island window lakes. However, it has much shorter residence times and so pH presumably more closely reflects the unmodified pH levels in the groundwater.

CLARITY

Water clarity has to date been assessed by Secchi depth readings and, because these readings have to be taken from a boat, there is little or no data for many lakes. Another issue with this method is that in the clearer lakes, Secchi depths may be greater than the lake depth, so that a true reading cannot be obtained. It is therefore difficult to draw reliable conclusions from some of the data. In general, clarity is strongly related to colour, so that the lowest Secchi values occur in the most highly coloured lakes. Clarity is also quite variable, and in the clearer lakes low values are often related to heavy rainfall. In the more coloured lakes variability is less and is generally unrelated to rainfall.

In clearer lakes such as McKenzie and Birrabeen, clarity is a potentially useful indicator of lake productivity. For the future, it is suggested that a different method for assessing clarity be implemented, one that can be undertaken readily at the lake shore and which is not subject to the same

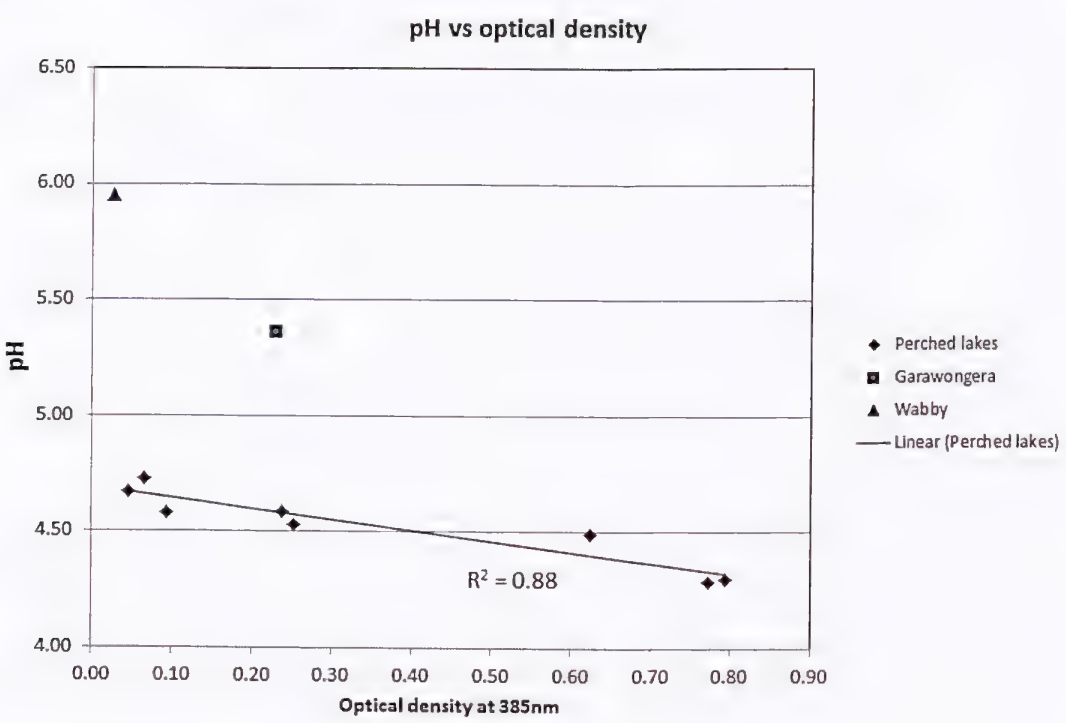

FIG.5. Correlation between optical density @385nm and pH.

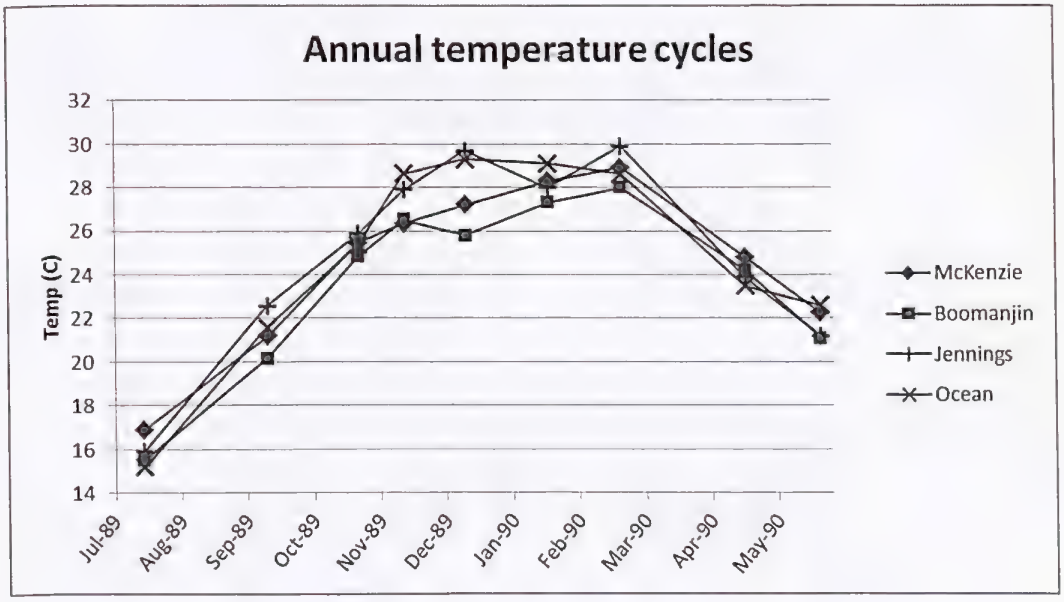

FIG.6. Annual temperature cycles in large and small lakes.

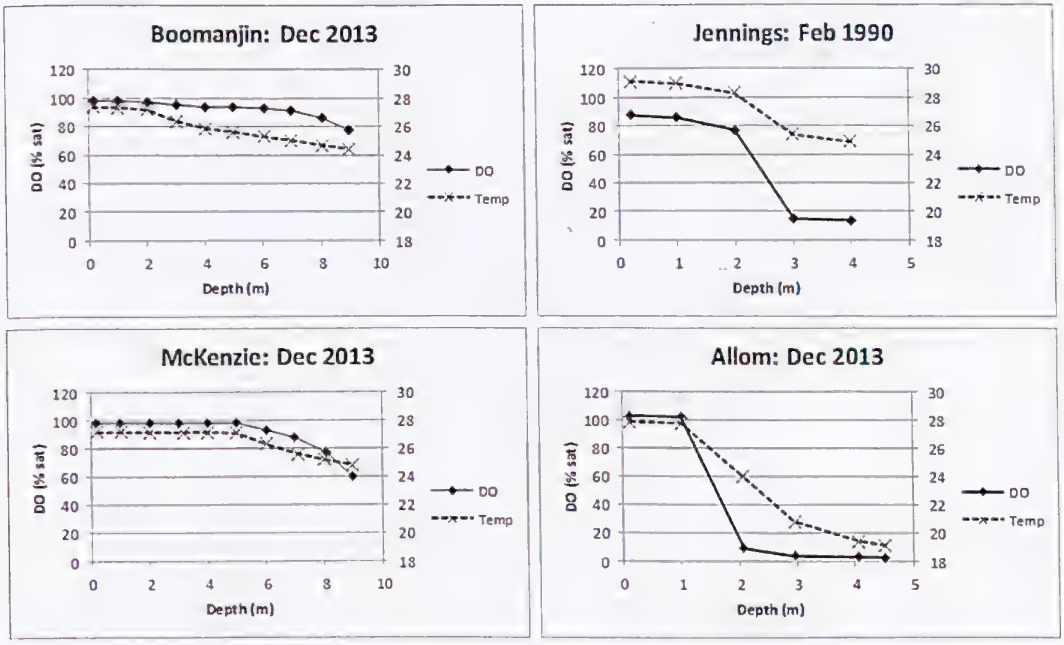

FIG.7. Examples of temperature and dissolved oxygen profiles in two large lakes (Boomanjin & McKenzie) and two small lakes (Jennings & Allom).

TABLE 5. Summary of available nutrient and chlorophyll a data for Fraser Island and North Stradbroke Island lakes.

Lake	Date	NH3		NO3		TN		FRP		TP		Chla	
		µg/L N or P										µg/L	
FRASER		n	Median	n	Median	n	Median	n	Median	n	Median	n	Median
Allom	1999-00	1	2	1	<2	1	320	1	2	1	4	2	<0.5
	2012-13	5	150 (19-160)	5	<2 (<2-4)	5	820 (710-840)	5	<2 (<2-5)	5	13 (12-14)	5	10 (7.2-14.7)
Basin	1999-00	7	130 (100-214)	7	10 (7-17)	7	360 (330-400)	7	2 (2)	7	2 (2-4)	8	<0.5 (<0.5)
	2012-13	3	63 (51-84)	3	24 (22-26)	3	340 (340-360)	3	<2 (<2)	3	3 (<3-3)	3	1.0 (0.4-1.6)
Benaroon	1989-90[a]		*		*		*		*	18	2 (1-7)	18	2.4 (<0.5-4.5)
	1999-00[b]	1	3	1	<2	1	175	1	2	1	2.5	2	<0.5
	2012-13[c]	3	11 (7-14)	3	8 (3-12)	3	370 (320-400)	3	<2 (<2)	3	5 (5-8)	3	1.0 (0.7-2.4)
Birrabeen	1989-90		*		*		*		*	27	1 (1-5)	27	1.5 (<0.5-4.8)
	1999-00	7	6 (2-25)	7	6 (2-79)	7	140 (120-200)	7	2 (2)	7	2 (2-4)	8	<0.5 (<0.5)
	2012-13	5	2 (<2-3)	5	<2	5	180	5	<2 (<2)	5	4 (<3-4)	5	1.4 (0.9-1.5)
Boomanjin	1989-90		*		*		*		*	27	2 (1-6)	27	0.8 (<0.5-2.4)
	1999-00	7	11 (4-37)	7	37 (8-45)	7	300 (185-380)	7	2	7	3 (2-6)	8	<0.5 (<0.5)
	2012-13	12	29 (5-32)	12	69 (61-93)	12	425 (40-46)	12	<2 (<2-3)	12	4 (<3-5)	12	<0.5 (<0.5)
Bowarrady	2012-13	9	50 (33-70)	9	6 (4-6)	9	350 (33-38)	9	<2 (<2)	9	3 (<3-5)	9	1.0 (0.5-2.1)
Garawongera	1999-00	1	2	1	<2	1	230	1	2.5	1	2.5	2	<0.5
	2012-13	3	58 (45-87)	3	<2 (<2)	3	440 (420-490)	3	<2 (<2)	3	5 (3-5)	3	1.6 (1.3-1.9)
Jennings	1989-90		*		*		*		*	18	3 (1-7)	18	1.1 (<0.5-1.9)

Lake	Date	NH3		NO3		TN		FRP		TP		Chla	
		µg/L N or P										µg/L	
FRASER (cont.)		n	Median	n	Median	n	Median	n	Median	n	Median	n	Median
Jennings (cont.)	1999-00	7	10 (4-34)	7	11 (6-40)	7	310 (200-380)	7	2 (2)	7	3 (3-5)	8	<0.5 (<0.5)
	2012-13	3	38 (31-39)	3	3 (3-7)	3	510 (480-640)	3	<2 (<2-2)	3	6 (5-7)	3	1.2 (0.9-3.5)
McKenzie	1989-90		*		*		*		*	27	1 (1-4)	27	0.8 (<0.5-2.0)
	1999-00	7	6 (2-28)	7	2 (2-8)	7	70 (70-90)	7	2 (2)	7	2 (2-4)	8	<0.5 (<0.5)
	2012-13	18	2 (<2-3)	18	<2 (<2-3)	18	70 (70-110)	12	<2 (<2-8)	18	3 (<3-8)	18	<0.5 (<0.5-0.9)
White	1999-00	1	3	1	<2	1	490	1	2	1	9	2	2
	2012-13	3	16 (14-30)	3	18 (7-22)	3	490 (480-550)	3	<2 (<2)	3	8 (6-9)	3	2.3 (2.2-3.5)
Ocean	1989-90		*		*		*		*	18	16 (5-24)	18	10 (2.7-13.9)
	1999-00		*		*		*		*		*	2	3.3
Wabby	1989-90		*		*		*		*	18	7 (3-12)	18	7.0 (2.1-13.4)
	1999-00	1	<2	1	<2	1	370	1	3	1	12	2	2.8
	2012-13	3	<2 (<2-2)	3	<2 (<2)	3	170 (170-180)	3	<2 (<2)	3	10 (9-11)	3	2.3 (0.5-2.5)
STRADBROKE		n	Median	n	Median	n	Median	n	Median	n	Median	n	Median
Brown	1996-02	154	4 (2-42)	154	<2 (<2-61)	154	430 (310-619)	154	<2 (<2-7)	154	13 (4-52)	154	8.5 (1.6-42)
Blue	1996-02	245	4 (2-67)	245	20 (2-48)	245	112 (30-364)	245	<2 (<2-10)	245	5 (<3-29)	245	1.2 (0.5-16)

a – Arthington (1990), b- Hadwen (2003), c-DSITI data, *- No data

issues as Secchi depth. One such is the black disc method (Davies-Colley 1988).

TEMPERATURE, DISSOLVED OXYGEN AND STRATIFICATION

The full seasonal data set collected during 1989-90 showed surface temperatures in all the lakes varied between 15 and 29°C. FIG. 6 shows annual temperature cycles in two large (McKenzie & Boomanjin) and two small (Jennings & Ocean) lakes. Winter temperatures are similar but the smaller lakes heat up faster than the large ones, reaching maximum temperatures in December, while the larger lakes do not attain peak temperatures until February. Boomanjin is more highly coloured than McKenzie but this does not appear to cause it to warm up any faster.

Average surface dissolved oxygen values were in the range 90-100% saturation in all lakes but values as low as 74% have been recorded. Even lower values can occur following destratification in some lakes.

During the cooler months, all the lakes are vertically well mixed. Stratification occurs during summer months but its intensity and temporal extent vary considerably. It is suggested that the main factors influencing this are exposure to wind action and water colour (Arthington *et al.* 1990). Wind and the resultant wave action reduce the degree to which stratification can develop while increased colour reduces light penetration and concentrates warming in the upper layers, thus increasing the likelihood of stratification. Lake size is also a factor, because it affects wind fetch and wave action.

In the larger lakes, McKenzie, Birrabeen, Boomanjin and Bowarrady, all of which lie in relatively low relief areas and are exposed to strong wind action, limited stratification is recorded occasionally during the summer months i.e. polymixis. FIG. 7 shows examples of the maximum extent of stratification recorded in two of these larger lakes, Boomanjin and McKenzie. Vertical variation in temperatures is only about 3°C and dissolved oxygen values in the deepest water remain above 60% saturation. Lake Jennings is smaller and less exposed to wind action. It can stratify more intensely than the larger lakes but is still essentially polymictic. Readings in FIG. 7, February 1990, show a vertical temperature range of 4°C and deep water dissolved oxygen saturation at 14%. Lake Allom is small and also very sheltered, being located in a steep sided depression. It stratifies intensely throughout the summer months i.e. a true monomictic lake, FIG. 7 shows an example from December 2013. The vertical temperature range is around 9°C and the hypolimnion is functionally anoxic. This has implications for the release of nutrients from the sediment, with potential impacts on the lake's trophic status.

TROPHIC STATUS

Nutrient and chlorophyll a data from three different monitoring events, 1989-90 (Arthington *et al.* 1990), 1999-2000 (Hadwen 2003) and 2012-2103 (DSITI data) are shown in Table 5. Values are expressed as medians, because values below detection limits occur frequently for some indicators and therefore use of means can be misleading. Ranges are included in brackets where there are >2 samples. The number of monitoring occasions and the number of samples vary considerably between lakes and between monitoring events but that is the nature of the available data. In fact there is a reasonable level of consistency within the results for each lake, with data for some indicators covering a span of up to 23 years in some lakes. The only nutrient measured in the first monitoring period (1989-90) was total phosphorus while a range of both nitrogen (N) and phosphorus (P) fractions were measured in subsequent monitoring events.

Total P concentrations were very low in most of the perched lakes. There were some small variations between monitoring events but not too much significance should be attached to these. The analysis of total P at these very low levels is problematic, particularly in these highly coloured waters, and also analysis techniques have improved over the past 25 years. Higher total P concentrations were recorded in two of the perched lakes, White and Allom. The elevated concentrations in White Lake are most likely to be due to its shallowness and the resultant increased sediment interaction. The higher total P concentrations in Lake Allom may be in part due to its high chlorophyll a concentrations but may also be related to the release of P from its sediments under anoxic hypolimnetic conditions.

The two Fraser Island window lakes, Ocean and Wabby, had generally higher total P concentrations than the perched lakes. The higher total P concentrations in Ocean Lake may be the result of its shallowness and the large number of birds that roost on it. The cause of the elevated total P levels in Lake Wabby is not known although it may be related to P levels in the regional aquifer. Total P concentrations in Eli Creek, which is fed from the regional aquifer, were in the range 7-8µg/L, based on three samples collected by DSITI in 2012. Filterable P concentrations were without exception very low in all lakes, mostly below the level of detection. Concentrations of all N species were generally higher and much more variable than for P. Total N concentrations show minimal correlation with chlorophyll a concentrations (apart from the high concentrations of both in Lake Allom) but they do weakly correlate with optical density ($r^2 = 0.47$), indicating that variability in humic material may be a partial cause of the variability of total N.

TABLE 6. Petroleum Hydrocarbon monitoring results.

Lake		Hydrocarbon Fraction			
		C15-C28		C29-C36	
	n	Mean	SE	Mean	SE
WATER (µg/L)					
McKenzie	5	77	20	68	23
Boomanjin	5	58	14	133	49
Bowarrady	4	142	36	134	61
Birrabeen	2	94	26	33	8
SEDIMENT (mg/kg)					
McKenzie	7	32	11	32	13
Boomanjin	4	20	12	18	10
Bowarrady	7	33	10	63	27
Birrabeen	2	35	21	77	44

Ammonia (NH_3) concentrations in all these oligotrophic lakes might be expected to be at the low concentrations that were detected in lakes McKenzie and Birrabeen. In fact, some lakes had much higher concentrations, including the completely pristine Lake Bowarrady. The most likely reason for this is the inhibition of nitrification in these low pH environments. Experiments with artificial lake acidification in Canada showed that at pH levels below about 5.4, nitrification very largely ceased and, as a result, ammonia started to accumulate (Rudd *et al.* 1988). The same process is probably occurring in Fraser Island lakes resulting in a similar accumulation of NH_3. Why NH_3 levels display so much variation between lakes is a matter for further research. The other main pathway for NH_3 removal is through phytoplankton uptake, but P levels are so low that phytoplankton may be unable to utilise the available NH_3.

Given that nitrification is inhibited, oxidised N levels in some lakes e.g. Lake Boomanjin, were higher than might be expected. A possible explanation for this is the ingress of oxidised N enriched groundwater. No measurements of oxidised N in groundwater are available but oxidised N concentrations in Wanggoolba and Eli Creeks, both of which are groundwater fed, were in the range 130 to 270µg/L N in 2012 (DSITI data). These concentrations are well above those in the lakes and so groundwater could potentially affect lake concentrations. However, this mechanism remains speculative.

Chlorophyll a concentrations in most of the perched lakes were consistently low in all monitoring periods. Slightly elevated concentrations occurred in White Lake, most likely related to its shallowness (Arthington *et al.* 1990). The one exception was Lake Allom which in 2012-13 had chlorophyll a concentrations five to ten times higher than other perched lakes. A single set of chlorophyll a samples collected previously by DSITI in June 2009 gave even higher values (25µg/L) and park rangers reported a visible bloom in 2006. Two separate causes for this greater productivity are proposed. Firstly, Lake Allom is situated adjacent to areas of wet sclerophyll forest that are more productive than the forest types surrounding most of the other perched lakes. The lake is also surrounded by steep slopes. Both factors would act to increase natural organic loading (leaf litter and run-off) to the lake, and so promote increased productivity. The small size of this lake may also be a contributory factor to this apparently natural eutrophication process. A second proposed cause is that, unlike other lakes in this study, Allom experiences a strongly anoxic hypolimnion for several months of the year. This would promote sediment release of nutrients, especially P, which appears to be strongly limiting in all the lakes. Total P concentrations in Allom are significantly higher than the other perched lakes.

The two window lakes on Fraser Island experience higher chlorophyll a levels than most perched lakes. As commented earlier, its shallowness (2-3m) and

the high numbers of roosting birds may be factors in Ocean Lake. The cause of elevated productivity in Lake Wabby is not known. Blue Lake, a window lake on the east side of Stradbroke Island is less productive, with a median chlorophyll a level of 1.2µg/L between 1996 and 2002 [n=230] (DSITI data). This however may be due to its short water residence times, which would limit phytoplankton biomass.

ANTHROPOGENIC CONTAMINANTS

The ever increasing number of visitors to Fraser Island has raised concerns about possible contamination of the lakes with pollutants such as petroleum hydrocarbons and sunscreen/insect repellent compounds. Concern has been focussed primarily on Lake McKenzie, due to high visitation and also to recent construction works to expand visitor facilities. To address these concerns, monitoring of these contaminants in Lake McKenzie and, for comparison, some less visited lakes, was undertaken during the period 2012 to 2013.

PETROLEUM HYDROCARBONS

Results for hydrocarbons in both water and sediment are shown in Table 6. Values for the lightest fraction (C10 – C14) in Fraser Island samples were all below detection limits and therefore only results for the two heavier fractions are reported here.

In absolute terms, the water concentrations were very low, in the microgram per litre range. At such low levels, advice from the analyst (Carswell pers comm) is that the method is not necessarily detecting petroleum hydrocarbons, but rather hydrocarbons of a natural origin e.g. tea tree oils. Of greater significance is the fact that concentrations of both hydrocarbon fractions in Lake Bowarrady, which has nil vehicle visitation, were higher than in Lake McKenzie.

Sediment hydrocarbon concentrations in McKenzie, Boomanjin, Bowarrady and Birrabeen were also uniformly low but again, levels in Bowarrady were slightly higher than in McKenzie. Thus, there is no evidence of anthropogenic contamination of Lake McKenzie with petroleum hydrocarbons.

SUNSCREEN AND INSECT REPELLENT COMPOUNDS

All the results for these compounds (see Table 2) from both water and sediment in all lakes were below the limits of detection. This outcome was somewhat unexpected, but is presumably a reflection of the rates of contamination, the large volumes of water in these lakes and the rate at which these organic contaminants break down. Weeks *et al.* (2012) note that the half-life of DEET is in the range of days to weeks i.e. a low persistence. It is possible that if samples were collected immediately adjacent to swimmers, then some of these compounds would be detected. However, this program aimed to assess systemic contamination of Lake McKenzie and other lakes and the results show no evidence of such contamination.

The toxicity of most these compounds is not well researched but there is some information on DEET. Costanza *et al.* (2007) reported levels in the range 8 to 1500ng/L in Australian coastal waters but suggested that these levels presented minimal environmental risk. Weeks *et al.* (2012) quote acute effect concentrations in the range 4 to 388mg/L. The data from this survey indicate that if these compounds are present in water, it is in the <100 ng/L range. For DEET, this is a factor of at least 40,000 below reported acute toxicity levels. While there is little information on the environmental effects of sunscreen compounds it seems unlikely that their toxicity is much greater than DEET, which specifically targets insects. The conclusion is therefore that the risk from contamination by these types of compounds is extremely low.

DISCUSSION

The data presented here come from a number of sources and span several decades. Nevertheless, the data exhibit a reasonable level of consistency. This affords some confidence that the combined data set provides a well-founded representation of typical water quality ranges in these lakes, despite some of the individual data sets being quite limited. It is therefore proposed that the range of indicator values in the combined data set does provide a suitable baseline for comparison with data collected in future monitoring programs. Although a number of data sets have been collated in this report, they are too limited and too variable in terms of both coverage and indicators to allow a statistically robust assessment of trends. Equally however, a subjective assessment of the data shows no evidence that any such trends exist. Ionic composition has remained virtually unchanged since 1964. Other physico-chemical indicators such as pH or conductivity exhibit fluctuations over time but with no obvious upward or downward trend.

With regard to trophic status, there is some indication that total P levels may have increased. However, given that (i) there are considerable technical difficulties with

total P analysis at such low concentrations in coloured waters, and (ii) the fact that these apparent increases occur in low use lakes e.g. Boomanjin as well as in high use lakes such as McKenzie, it is suggested that no great significance should be attached to these apparent increases. Nitrogen concentrations are much more variable than phosphorus concentrations. Some contributory factors to this have been proposed including inhibition of nitrification and variability in humic acid concentrations, but other factors may be involved. The variability of nitrogen concentrations and the very limited available data make it impossible to draw any reliable conclusions about trends for this indicator. Chlorophyll a concentrations are relatively low and consistent in most lakes, with no indication of any increasing trend, including Lake McKenzie.

The one exception to the above is Lake Allom where there have been apparent increases in both chlorophyll a and nutrient fractions. However, as the 1999-2000 data is based on only one or two results it is difficult to draw any firm conclusions.

The absence of apparent trends in the data indicates that, to date at least, the effects of tourist visitation on water quality have not been very significant. Lake McKenzie in particular shows no real evidence of a decline in water quality despite very high visitation rates. However, this should not be a matter for complacency. The large and ever increasing numbers of people visiting and swimming in Lake McKenzie must present some level of risk to the lake water quality, particularly its trophic status, although the magnitude of this risk is not known. The long water residence times and the oligotrophic nature of this and other lakes would certainly enhance this risk.

The use of traditional water quality indicators alone to predict visitation effects is subject to limitations. For example, it has been suggested that water quality indicators may not demonstrate measureable responses until some significant and perhaps irreversible change has occurred (Hadwen *et al.* 2005). Regardless of the extent to which this is true, it does raise the question of whether additional indicators should be employed to assess lake health. Hadwen *et al.* (2005) propose that periphyton attached to reeds may be a useful indicator, particularly as reeds are static and therefore allow comparison of areas close to and far away from visitor access points. Water quality is less amenable to this type of spatial analysis as wind and wave effects ensure that most lakes are well mixed in the horizontal plane.

Isotope experiments (Hadwen 2002) have shown that periphyton and the reeds themselves rapidly take up spikes of ^{15}N, so it is possible that they would respond more rapidly to nutrient enrichment than the phytoplankton. On the other hand, comparison of periphyton biomass in Lake McKenzie at impact and control sites showed no significant differences (Hadwen *et al.* 2005). Nevertheless, this and other new indicators are worthy of further consideration.

The trophic status of most perched lakes can be considered oligotrophic but Lake Allom is an exception, with chlorophyll a concentrations well above those of other perched lakes. It is surmised that this is due to a combination of a more productive catchment, its small size and the regular occurrence of an anoxic hypolimnion. Lake Allom has always been known for its abundant turtle population and it is suggested that this is related to the long-term higher levels of productivity in this lake compared to most others. Lake Allom does experience moderate visitation but this is mainly to view the freshwater turtles (feeding them is strongly discouraged) rather than to go swimming. It seems unlikely that this level of visitation would have had significant impacts on its trophic status when vastly higher visitation to Lake McKenzie is having no apparent effect.

To test the importance of hypolimnetic hypoxia in determining trophic status it would be of interest to compare Lake Allom with other Fraser Island lakes which experience intensive stratification e.g. Hidden Lake. Brown Lake on Stradbroke Island has similar total P and chlorophyll a levels to Lake Allom but stratifies much less often, so other factors may be involved. One of these may be Brown Lake's more disturbed catchment, which includes a golf course.

Concentrations of some nutrient species are quite variable but levels of soluble P (measured as filterable reactive phosphorus) are uniformly at or below levels of detection in all lakes. This suggests that phosphorus is a likely key limiting nutrient for all Fraser Island lakes. Levels of inorganic N (NH_3 + oxidised N) vary from >50µg/L in some lakes to 2µg/L in others, so while nitrogen limitation may be significant in some lakes it is unlikely to limit growth in others. Algal bioassays of nutrient limitation in a number of lakes

(Hadwen 2002) gave results that were inconsistent and appeared to be lake-specific. Given the exceedingly low filterable reactive phosphorus concentrations in all lakes, it would be expected that P addition alone would have stimulated growth everywhere, but this did not appear to be the case. It is possible that the depauperate sandy soils characteristic of these catchments may also result in limitation by many micronutrients, which may be equally important as phosphorus or nitrogen limitation.

Given the extremely high and ever increasing level of visitation to Lake McKenzie it would seem prudent that some ongoing monitoring of its condition should be undertaken. Such a program should include one or two moderate use lakes and at least one undisturbed lake as a reference. The program should continue to include some water quality indicators but the addition of biological condition and process indicators should be carefully considered. Advances in automated monitoring technology also present opportunities for acquiring data that are much more temporally intensive, and thus more informative, than occasional field surveys. For example, continuous measurement of lake clarity would allow much earlier detection of trends in phytoplankton populations while similar measurements of surface and bottom water dissolved oxygen concentrations could detect changes in overall lake productivity. Satellite image spectral analysis might also provide long-term data on lake clarity.

Ongoing monitoring of contaminants such as sunscreens or petroleum hydrocarbons is of lower priority. Based on the data presented here, there should be no further monitoring of hydrocarbons. Occasional assessment of sunscreen/insect compounds, in Lake McKenzie only, may be justified.

It is also suggested that a more comprehensive monitoring of both total visitation rates to the island and visitation to individual lakes be implemented. This would provide key information for quantitative assessment of tourist impacts into the future.

Without some form of ongoing assessment, there is a real possibility that incremental deterioration in the quality of Lake McKenzie's waters and aquatic ecosystems will occur without management being aware of it. Such changes may be difficult to reverse and may impact on the pristine nature of this, and potentially other lakes, which is their main attraction for tourists.

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AUTHOR PROFILE

Andrew Moss is a Principal Scientist with the Queensland Department of Science, Information Technology & Innovation. He has been involved in monitoring and assessment of Queensland waters for more than 30 years. He is the author of the Queensland Water Quality Guidelines.

ANNUAL REPORT, ROYAL SOCIETY OF QUEENSLAND, 2015 – 2016

EDWARDS, G.

OVERVIEW

This report covers the period from September 2015 to August 2016. The Society has had an active year with several inspiring events as well as timely publication of our journal, volume 120 (2015) *Proceedings of the Royal Society of Queensland*. It is noteworthy that the *Proceedings* continues to be supported by the scientific community for publications of relevance to Queensland. This year Council undertook a major consolidation of the membership list by following up many members whose membership had lapsed or whose details were no longer current. Our newly consolidated membership list is now much clearer with memberships rising. We are gratified that many new members are opting to join for three years. The Society continues to be respected as the pre-eminent scientific society in Queensland and has enjoyed the hospitality of our Patron, His Excellency the Governor of Queensland.

Some negatives reported last year remain. The capacity of Council is limited by the absence of a designated Treasurer. Cash flow remains negative. The time demands of organising events has constrained the time of Councillors available for policy formulation. In particular, the Society could well invest more time in pursuing the initiatives that we have commenced. Every one of the meetings we have held in the past 12 months has raised interesting insights upon which new practical or policy-based projects could be launched. To take advantage of these leads, we will require some more members to volunteer.

In public affairs, governments of both major persuasions continue to override or ignore scientific advice as to the limits to economic growth and the stresses being faced by natural ecosystems. The Society can become more prominent in public debate in defence of science and scientists.

This report summarises some highlights of the year. For more detailed accounts, please refer to the Newsletters of which 13 have been issued.

CORPORATE AFFAIRS

MEMBERSHIP AT SEPTEMBER 2016

Highlights:

- Three current RSQ life members of long-standing (Dr A Bailey, Dr J Jell, Dr J O'Hagan)
- Three eminent scientist-members endorsed by Council for life membership (Prof Ray Specht, Prof Calvin Rose, with Prof Trevor Clifford awaiting investiture)
- 84 current members, with a further 13 pending renewal
- Following consolidation of the membership list during the year, membership is now increasing.

Given the high fixed-cost component of printing the *Proceedings*, the Society's cash flow deficiency would disappear if it were able to double the number of members. Council is keen to engage work experience students and also to hold information sessions at our universities with a view to raising the profile of the Society.

Recently I calculated the number of members with whom I or other Councillors have had personal, recent, active contact, such as through contemporary involvement with activities. I counted 55, or approximately one half of the total membership. I interpret this as an indication of an active, engaged membership and a good portent for the future.

We regret to inform members that Life Members Drs Alan Bartholomai and Donald Tugby passed away in late 2015.

COUNCIL MEETINGS

Two meetings of Council were held during the year, on 24 October and 14 May. Most Council business is transacted by email and telephone.

MEMBERS' SURVEY

During 2014 and 2015, members Hernan Retamales and Kurt Martin contacted about half of the members to discuss their expectations of the Society. Their report has been finalised. Members generally supported the scope of the Society's activities and of

its publications, especially the signature *Proceedings*. Most comments proposing improvements were to add activities rather than desist from anything we have been doing.

WEBSITE

A new website developed by Clear Media on instructions from our sponsor Avantix was handed over to the Society on 20 May. Some development is still required, such as to make it possible to join online. We record our appreciation of the *pro bono* support of Duncan Lord, CEO of Avantix and his staff.

The website has full-text search capability of all issues including the *Transactions of the Philosophical Society of Queensland* (from 1859). This should greatly improve the exposure of the journal to an international audience. Current policy is to make issues prior to 1956 available free of charge, but to seek payment for articles after that – except for members, who can enjoy free access to any issues. Free access for members has not been automated, so requests from members should be directed to the Society at its official email address.

The agency Informit handles requests for articles for which a charge is made.

Following web-publication of Past President Paul Sattler's memoirs, member Alan Lauder has granted rights to web-publish his book *Carbon Grazing*. All members are invited to make any unpublished work and (subject to copyright) any published work available for wider distribution through this avenue.

LIBRARY

Council is pleased to report that Meg Lloyd has agreed to be Honorary Librarian. Ms Lloyd is on the staff of Queensland Museum and curates the Society's library of some 20,000 volumes. Members enjoy free access to the Society's library, by appointment with Ms Lloyd.

PROCEEDINGS OF THE ROYAL SOCIETY OF QUEENSLAND

Honorary Editor Barry Pollock oversaw the production of volume 120 of the *Proceedings of the Royal Society of Queensland* and upheld the high standard of the journal, as well as imposing tight discipline on the deadlines, enabling us to publish the volume on time in 2015. Volume 121 is on track for publication before the end of 2016. Special thanks are given to Rennie Fletcher who does the type-setting and layout for the journal articles. The cover artwork for volume 120 was done by a local artist Ian Millar, who provided an excellent illustration at no cost to the Society. All papers submitted for publication in the *Proceedings* are subject to review by anonymous referees who are experts in the particular subject area of the submitted paper. Some papers are not accepted as they do not meet scientific standards or other criteria set out in the *Guide to Authors*. The efforts of the anonymous referees are very much appreciated.

EVENTS

INVESTITURE OF PROF RAY SPECHT AND LAUNCH OF PROCEEDINGS – 16 DECEMBER 2015

A meeting at the Eco-Sciences precinct in Boggo Road and well attended by members and guests celebrated Prof Specht's long career from 1948, when he joined the American-Australian Scientific Expedition to Arnhem Land, to at least 2013 when he co-authored an entry into an international encyclopaedia. A career spanning 65 years! With the assistance of Editor Dr Barry Pollock, Prof Specht launched Volume 120 of the annual *Proceedings*.

GOVERNOR'S RECEPTION – 3 MARCH 2016

About 80 members and guests attended a reception at Government House at which His Excellency the Governor of Queensland launched the digitised website. A thoroughly enjoyable time was had by all. Attendees greatly enjoyed reconnecting with former friends and colleagues. We were honoured that the Hon Leanne Enoch MP, Minister for Innovation, Science and the Digital Economy, attended.

PUBLISHING SCIENCE – 10 MARCH

Editor Barry Pollock and I were delighted to have an audience of some 35 people at Boggo Road for a lunchtime forum to showcase the *Proceedings* and discuss science outreach and science publication generally. The vigorous attendance and the warmth of interest were noteworthy. The audience was mainly Queensland public servants and was quite distinct from that of the previous event in December at the same location.

COMMUNITY HEALTH, CAIRNS – 29 MAY

Some 22 representatives from the Cairns and region health sector attended a workshop on the broad theme of Community Health - the evidence base for investment. The workshop was sponsored

by the Australian Institute of Tropical Health and Medicine with the support of the Cairns Institute. This stimulating event was organised by consultant Jacqui Lavis *pro bono* and addressed by member Kurt Pudniks.

On a nostalgic note, the Society's interest in community health dates back to its foundation in 1859. The first paper in 1859 was by Dr Frederick Barton on asphyxia, the second on ventilation of buildings. Other early papers covered public sanitation and the water supply for Brisbane. The second President Joseph Bancroft from 1884-1897 was a surgeon with an interest in environmental health, disease transmission by parasites and plant ecology. Given that the first exploratory meeting of the Philosophical Society was held prior to official declaration of the colony, we can legitimately argue that our interest in public health predates that of even the Queensland Government. The scope of the Society's activities is and long has been "science and the application of science", fields of knowledge that are central to the challenges facing community health.

It was intended that the event would focus on the biological basis of ill health, especially preventative health and biomedical aspects. This was borne out: the afternoon zeroed in on the foundation of chronic disease in poor nutrition at an early age. Discussion focussed on the potential of a sugar tax to create an income stream to fund primary prevention activities. A submission to the Queensland Government and press release are in train.

MINE REHABILITATION – 14 JUNE

Triggered by a presentation made by member David Marlow at the 2015 AGM, a small group of members met on 14 June to discuss whether there might be a role for the Society in advancing the cause of rehabilitation of abandoned and declining mines and gas fields. The group has drafted a brief for consideration by Council.

MAINTAINING QUEENSLAND'S REGIONAL NATURAL CAPITAL – 29, 30 JUNE

Some 40 attendees including a good turnout of members participated in a thoroughly interesting forum at the Global Change Institute on 29 and 30 June. Attendees heard some 15 thoughtful and original presentations. Congratulations to Members Alistair Melzer and Cate Melzer who organised the event. The presentations are loaded on the website of Sustainable Queensland http://sustainablequeensland.info/. Scientific insight about what is required to maintain conservation attributes on the protected area estate and also for conserving environmental attributes on privately managed grazing land seems to be far ahead of the capacity of governments and other entities to apply that knowledge. The meeting resolved to prepare a short Position Paper outlining the need for improved policy and budget provision for maintaining conservation values in regional Queensland. I expect that the Society will participate in presenting this submission to government.

A highlight of the symposium was investiture of Prof Calvin Rose AM as Honorary Life Member. Prof Rose was Foundation Dean of Australian Environmental Studies at Griffith University. He was the prime mover behind the Griffith EcoCentre on the Nathan Campus, opened in 2001 as a resource centre promoting sustainable development and encouraging community participation in environmental issues.

LAUNCH OF ASSA REPORT ON COMPARATIVE ADVANTAGE – 7 SEPTEMBER

The Academy for the Social Sciences in Australia approached the Royal Society of Queensland to host an event to publicise a new report on potential opportunities for Australia to develop comparative advantage, notably through research and innovation. The Society agreed, on condition that it could nominate a respondent who would point out the biophysical limits to economic growth and the constraints upon throughput of resources and materials from the Australian environment. We believe that these aspects are underplayed in the ASSA report. Member Prof Ian Lowe AO agreed to take up this challenge.

AWARDS

PAUL SATTLER – UQ GATTON GOLD MEDAL

Past President Paul Sattler OAM was awarded the University of Queensland Gatton Gold Medal at a ceremony on the campus on 15 December. Among a career lifetime of other achievements, Paul's pioneering work in identifying regional ecosystems and applying this science in the 1990s as a tool for augmenting the National Park estate was a primary basis for the award.

PROF SEAN ULM – FELLOW OF AUSTRALIAN ACADEMY OF THE HUMANITIES

Member Assoc. Prof Sean Ulm, Cairns-based ARC Future Fellow at James Cook University, was elected a Fellow of the Academy late in 2015. Prof Ulm is

a specialist at the forefront of human-environmental studies in Aboriginal archaeology, particularly from coastal contexts in northern Australia and the Pacific.

GO EXTINCT! GAME WINS THE HUXLEY PRIZE

Member Ariel Marcy has been awarded the 2016 TH Huxley Award by the Society for the Study of Evolution for her work with *Go Extinct!*, which will connect educators in the US and Queensland. The Huxley Award recognises outreach and education achievements by early and mid-career scientists. Ariel Marcy is a Fulbright Scholar, a current PhD candidate at UQ, an entrepreneur and educational game designer behind *Go Extinct!,* a board game powered by the "most profound idea in biology: evolutionary trees".

NORTH QUEENSLAND FESTIVAL OF LIFE SCIENCES 2015

At the celebration in November 2015, Member Mohammed Shorab at James Cook University presented the second Royal Society of Queensland awards to:

- Tahnee Bridson (College of Medicine and Dentistry) – *Diabetes: A contributor to TB in Tropical Australia.*
- Roni Nughra (College of Public Health, Medicine and Veterinary Sciences) – *In-silico bioinformatics approach for the identification and characterisation of allergens from the Pacific Oyster (Crassostrea giga).*

Each student won entitlement to a small cash prize and two years' free membership of the Society.

PROF TREVOR CLIFFORD OAM

Long-standing Member Emeritus Prof Trevor Clifford was honoured in the June 2016 Queen's Birthday lists with a Medal in the Order of Australia. The citation was "For service to botany and to tertiary education". Council had previously resolved to invest Prof Clifford with honorary Life Membership, at a ceremony to be held in 2017.

NEW BOOK BY PROF DILWYN GRIFFITHS

Long-standing Member Dilwyn Griffiths published *Freshwater Resources of the Tropical North of Australia: a Hydro-Biological Perspective* during the year. His account presents an overview of the freshwater resources of the tropical north of Australia and the major developments that they have supported, starting with the post-World War II developments. That period saw the construction of major water storages and water-related infrastructure, leading on to more recent developments with their increasing emphasis on sustainability and protection of the environment. The major emphasis is on recent projects but earlier development is also described to provide an overview of how thinking on the exploitation and management of this precious resource has evolved.

PROJECTS

COMMUNITY INFRASTRUCTURE

The insights presented at the June 2015 symposium on infrastructure co-sponsored with Engineers Australia Queensland and Institute for Future Environments, Queensland University of Technology have still not been heeded by governments who continue to conceive of 'infrastructure' as being confined to big transport projects. There is scope for additional advocacy on the value of scientific research as a form of infrastructure and a precursor to the 'innovation' that remains on the national government's agenda.

STEM EDUCATION

The primary action arising from the July 2015 brainstorm was development of an 'information portal' for accessing authoritative science education programs and projects evaluated as being consistent with the curriculum, for use by teachers. On 28 September 2015 a meeting of eight organisations including the authorities resolved to form an independent reference group to oversee the introduction of the portal. The meeting accepted a model of distributed governance: the bodies independently participate through their representatives as an independent expert panel. Member Dr Satish Choy volunteered to be the Society's representative.

Funding was provided by the Office of the Queensland Chief Scientist which engaged the Queensland Government's information management experts to prepare contract documentation. Then the Office of the Australian Chief Scientist was so impressed with the concept that they have decided to develop a national portal, with Queensland's being a pilot project. It is hoped that a trial version will be ready by the end of 2016.

To maintain momentum in STEM education, the Society endeavoured to reconvene the brainstorm in September, but the proposal was aborted when two key presenters became unable to attend.

RESEARCH FUND

Members Dr Raghu Sathyamurthy, Dr Alistair Melzer and Assoc. Prof. Joachim Ribbe have volunteered to form a Steering Committee to take our Research Fund to the next stage of development. This will entail preparing promotional materials, developing a fund-raising strategy and bringing the Fund to the attention of the science community and the philanthropic community. Progress has paused pending legal validation of a prospectus by pro bono lawyers Sparke Helmore.

Members of retirement age are invited to remember this Fund during their estate planning. The fund is tax deductible and perpetual naming rights are available for significant bequests.

STEWARDSHIP INCENTIVES PAPER

A writing team of members Heather Douglas and Chris Kahler with geographer Michael Gutteridge is joining with me to produce this paper. A draft of the paper suitable for expert review is expected to be available by the date of the AGM. The foundation of the model outlined in the report is a finding that market prices for food and fibre commodities are not generous enough to return discretionary funds to pastoralists over and above the cost of production, to enable them to regenerate their natural land asset.

THANKS

I acknowledge the loyal service of members of the outgoing Council - Ross Hynes, Ben Lawson, Barry Pollock and Craig Walton. They have held high the reputation of this long-standing society throughout the past year. The same applies to two Councillors, Martin Wurzinger and Ramola Yardi, elected at the 2015 Annual General Meeting but who resigned during the year.

A special thanks is due to member Tara Horner who acted as Events Coordinator for much of the year and was of outstanding assistance in organising some events, notably the Governor's reception on 3 March. I thank other volunteers who have contributed to the well-being of the Society through the year and all those members who contributed to the success of events simply by turning up.

In summary, the future of the Society remains bright and, in this era of fragmentation of public institutions, its role of building knowledge about science and the application of science through education and policy is as valuable as it has ever been. I encourage all members to renew their membership, in order to enable the Society to fulfil its special mission.

Geoff Edwards
President
On behalf of the Council of the Royal Society of Queensland

UNIVERSITY OF QUEENSLAND GATTON GOLD MEDAL ADDRESS, 2015

SATTLER, P.S. OAM

The address delivered to the Graduates in Agriculture and Food Sciences, Gatton Campus, 15 December 2015, upon receipt of the University of Queensland Gatton Gold Medal.

68 Sanctuary Drive, Mt. Cotton, Queensland 4165, Australia. paulsattler@bigpond.com

What an honour to receive the UQ Gatton Gold Medal. I must however, acknowledge my colleagues: it is 'on their shoulders that I have stood'.

To the graduates: congratulations! Forty-four years ago I was seated exactly where you are and little did I think that I would have the pleasure of addressing today's graduates. In thinking about this address, there are a few things I would encourage you to consider as you pursue your careers.

Firstly, the importance to question, and to question underlying assumptions of policies and projects, of management and research. Six weeks after I finished College, specialising in rural technology, I was employed in a different field, environmental management. But like you, I had been taught to enquire and apply systematic and scientific techniques to problem solving: that stood me in good stead as I pursued a new career.

Let me share an example of the importance to enquire and to test assumptions that I was involved in from College to the early days of my career. Whilst at Gatton, I had specialised in the development of 'improved' tropical pasture species introduced from overseas.

Millions of dollars were spent by the Queensland Department of Primary Industries and the Commonwealth Scientific and Industrial Research Organisation researching the introduction of these species onto the highly infertile and acidic coastal soils of south-east Queensland. In the mid 1970s, it took one political decision; the removal of the phosphate bounty, and the industry was swept away, being uneconomic.

Worst still in my new found role, I saw that many of these introduced species became environmental weeds. Some of these species and additional species introduced in the tropics since that time, such as Gamba grass, *Andropogon gayannus,* have created major fire risks with fuel loads that threaten the survival of natural ecosystems.

Furthermore, little consideration was given to the importance of these coastal areas for alternative land uses. These lands have high value for tourism and recreation, for ecosystem services such as protecting our valuable estuaries, and for biodiversity.

One example of their biodiversity value is that our wildflower heathlands are second only to rainforests for plant species diversity.

In recent years, one species that beekeepers know as Jelly Bush, *Leptospermum polygalifolium,* has been found to produce honey that is very active for its antibacterial properties, and is high in the chemical marker methylglyoxal (MGO). It is Australia's equivalent to the New Zealand Manuka honey and after extensive clinical analyses, it is being increasing used in medicine and burns units. It also brings up to $200/kg. Unfortunately, most of its coastal habitat has been lost.

So question and test assumptions, especially be aware of the broader context; the assumptions underlying this pasture improvement scheme for beef production on the coastal lowlands were ill considered.

It is also important to enquire into underlying attitudes particularly when trying to introduce changes in land management. One of my difficult challenges was to convince people in western Queensland of the value of establishing national parks. It was only through understanding existing attitudes that strongly held beliefs could be discussed and addressed. This together with demonstrating that a scientific rationale was being used to systematically select land for conservation, it was not an ill-defined land grab, that national parks were progressively accepted as a legitimate land use.

The second point I would encourage you to consider, is the importance of engaging in multi-disciplinary approaches to problem solving.

Many of you will specialise in your careers and that is essential. We must drill down to understand how things work and to make new discoveries. Specialisation may also be at a variety of scales, e.g., it could be at the genetic, species, ecosystem and landscape scale.

However, over the course of your careers the world's population may increase by a further 2 billion people. How will food security be achieved when as an example, only minor rises in sea level, together with sun stress, will seriously affect rice production on the deltaic floodplains of Asia upon which millions of people depend?

Closer to home, let us consider that the major proportion of the Australian land mass is rangeland. How will we sustainably manage these landscapes in a warming climate with changing rainfall patterns? What will be the appropriate management for rangelands of marginal economic status, that occupy one third of the continent (Sattler 2007 after Dames and Moore NRM 1999), and for the extensively degraded areas that have been overgrazed by stock, and 'roos in some locations, when farm economics provide no scope to spell land and repair?

Australia is a world leader in animal husbandry, the status of this campus bears testament to that: but are we leaders in managing those landscapes within which our animals graze? Rangeland research and monitoring is essential to answer this question and to establish models of profitable and sustainable production.

Closer in, what will be the solutions for sustainable management of our fertile agricultural lands from threats such as from salinity? A visit to the wheat-belt of Western Australia reveals 2.5 m ha now poisoned from salt.

Continuing broad-scale vegetation clearing remains a significant environmental issue in Queensland. In parts, where vegetation clearing is more recent, the salt is still well down in the soil profile. However, in some ground water flow systems of the Murray-Darling Basin in Queensland, a ten-fold increase in salinity has been modelled as potentially occurring over the next 50 years (Dawes, *et al.* 2003).

Solutions to control salinity will entail the development of integrated land use strategies that optimise the mix of food and fibre production, water quality, water yield, carbon capture and biodiversity for each catchment.

To address all of these management issues will require both specialists and those who can reach across the multi-disciplinary space and move into new and emerging roles. We cannot afford to work in silos.

Thirdly, I would encourage you to look for opportunities to integrate nature conservation with production systems. Over my career I have been fortunate to see great successes in developing the protected area system to conserve the rich and endemic biodiversity of this continent (Sattler 2014). Gaps in developing a fully representative system still exist, particularly in the semi-

arid woodlands, shrublands and grasslands of Australia's rangelands, and to protect our inland and savannah wetlands. These areas are acknowledged priorities, at least at a technical level, and national park consolidation in these areas needs to continue apace.

However, off-park conservation on private lands has not been as successful. The National Land and Water Resources Audit's *Terrestrial Biodiversity Assessment of Australia* (Sattler and Creighton 2002) revealed that whereas our protected area estate was achieving measured success in the protection of threatened species, as one indicator, such success was not evident through off-park conservation efforts.

The Australian Auditor-General (2008) also found that there had been little evidence of any substantive movement towards landscape repair over much of the last decade after substantial funding of natural resource management programs.

This means that greater effort is required to develop whole of landscape solutions for the protection of biodiversity. We need to encourage and resource those who can make the links between production, environmental, economic and policy/political systems. These activities substantially involve the public interest and should not be left to market forces alone. Secure public resourcing of regional natural resource management organisations is required as staffing based on short-term contracts does not readily allow for advisors to become effective members of the rural community to support management change. This will be a challenge for those working in this area and highlights the need for you to develop professional and local networks.

Natural resource planning must further develop to include identifiable biodiversity as well as broader environmental outcomes. This will require the informed and focused integration of nature conservation with agriculture.

Finally, on a completely different note, I would encourage you all to join the Gatton Past Students Association. Every year there is a lunch or dinner in various centres and I have always found them great fun. It is interesting to meet up and discuss where careers have taken fellow graduates, and to swap tales of College days.

Again congratulations to the graduates, may you have exciting and fulfilling careers. You have chosen the right profession for that, and to make a difference for the benefit of others. Good Luck!

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AUTHOR PROFILE AND ACKNOWLEDGEMENT

Paul Sattler is a past President and current member of the Royal Society of Queensland.

Extract from Citation for the Gatton Gold Medal 2015. Professor Peter Høj, Vice-Chancellor, University of Queensland:

'Mr Sattler has significantly influenced nature conservation and natural resource management in Queensland and nationally.

'In 1972 he became the Queensland Government's first ecologist ... (and) although he quickly realised that his role would be complicated by a collision of competing interests, he stayed the course and established an-evidence based, strategic platform for biodiversity conservation.

'In the early years of his career Queensland's national parks estate was piecemeal and covered only 0.68% of the state. 'By 2000, when Mr Sattler left the Queensland public sector, the estate had increased more than fivefold and covered 6.7 million hectares across all biogeographic regions. 'Importantly, his approach ensured comprehensive representation of Queensland's rich biodiversity. 'This sometimes involved protection of places ...that are little celebrated. 'So while well-known coastal areas ... gained protection ... (many) ecosystems that would otherwise be seriously degraded have been protected ... .

'At the turn of the millennium, Mr Sattler ... was lead author of the first detailed, multi-scale assessment of the nation's terrestrial biodiversity, for the National Land and Water Resources Audit.'

ROYAL SOCIETY OF QUEENSLAND, AWARD OF LIFE MEMBER

EMERITUS PROFESSOR HAROLD TREVOR CLIFFORD OAM

INVESTED AS LIFE MEMBER, DECEMBER 2015

Emeritus Professor Harold Trevor Clifford was born in Melbourne on 18 April 1927. He worked at the University of Melbourne from 1948 to 1953 as a Botany Tutor, Senior Tutor and then part-time Lecturer. He took up an appointment as Lecturer in Agricultural Botany at the University College of Ibadan, Nigeria from 1955 to 1958. This was followed by a long career at the University of Queensland from 1958 to 1992, commencing as Lecturer in Botany. He retired in 1992 as Professor Emeritus. Professor Clifford was also Visiting Professor, Agricultural University, Beijing, China, 1990; and Visiting Professor, University Nusa Cendana, Kupang, Indonesia, 1994. He has also been an Honorary Research Fellow (Geoscience), Queensland Museum, since 1995; and an Honorary Research Associate, Queensland Herbarium, since the 1990s.

Throughout his career Professor Clifford received many scholarships and awards from prestigious funding bodies including the Nuffield, Carlsberg German Cultural, and University of Queensland Foundations. He recently was awarded an Order of Australia Medal for his contribution to botany and higher education.

Professor Clifford has many scientific publications including some thirty books and two hundred research papers including:

- 'Queensland Fossil Plants', 2015.
- 'Etymological Dictionary of Grasses', 2007.
- 'The families of the Monocotyledons', (with R.Dahlgren), 1985.
- 'The monocotyledons, a comprehensive study' (with R.Dahlgren), 1982.
- 'Grass Identification' (with L Watson), 1977.
- 'An Introduction to Numerical Taxonomy' (with W Stephenson), 1975.
- 'Keys to the Families of Queensland Flowering Plants (Magnoliaphyta)', (with Gwen Ludlow).
- 'Ferns, Fern Allies and Conifers of Australia', (with J. Constantine).

He also produced several student text books for the identification of Queensland plants. Archives of his papers are held by the Hunt Institute for Botanical Documentation, and at the Basser Library (Australian Academy of Science). Fryer Library, University of Queensland also holds correspondence in relation to the Harold Trevor Clifford Collection.

Other memberships and positions held by Professor Clifford are: Member, Linnean Society, London, United Kingdom, since 1965; Fellow, Australian Institute of Biology; Former Member, Flora of Australia Committee, Australian Academy of Science; Australian Cultivar Register (Representing the Curator, Brisbane Botanic Gardens); Membership Committee, Australian Institute of Biologists; Honorary Advisor, Brisbane Botanic Gardens.

Trevor Clifford married Gillian in 1953 and together they have three children Marian (born in Durham), Kate (born in Nigeria), and Daryl (born in Brisbane). He has nine grandchildren and three great grandchildren.

His family has advised that "Holidays were always spent on educational adventures to national parks, museums, botanic gardens and so on. We were spoilt to be able to go on these excursions with such a great naturalist. Every walk was full of information about the environment – geography, geology, botany and ecosystems. I am not sure we always valued this however our childhood friends often relate stories of their 'educational adventures' with our family. Recently he took his 5-year-old great grandson for his first educational adventure on the city cat. He can also still outwalk his grandchildren most days."

His professional enthusiasm continues today not only as an Honorary Fellow at the Queensland Museum and The Herbarium, but he still propagates plants from seeds collected by all and sundry around Australia. Professor Clifford says that he was fortunate to be paid to pursue his hobby. His family observed Petrie dishes and notes scrawled on scraps of paper, (the back of an envelope was always a sufficient start to the next book) could be found neatly stacked around the house as he scrutinised, measured and documented his discoveries.

Kate Charters

ROYAL SOCIETY OF QUEENSLAND, AWARD OF LIFE MEMBER

EMERITUS PROFESSOR CALVIN ROSE

INVESTED AS LIFE MEMBER, JUNE 2016

Calvin Rose was born on 27 November 1929 at Dubbo, NSW to school teacher parents. He attended North Sydney Technical High School where he graduated Dux of School, gaining both a scholarship and bursary for Sydney University. Bachelor degrees from that university in science and aeronautical engineering were granted in 1949 and 1951, respectively. Calvin was first employed as an aircraft design engineer with the Commonwealth Aircraft Corporation, Melbourne. The impending demise of the design activity in Australia after the Second World War, together with other interests, led to him to teaching and research appointments in the Department of Physics, Makerere University College, Uganda, from 1954 to 1963. Before departing Australia for East Africa, Calvin married Mavis (now Dr. Rose).

Makerere University College was linked to London University, from which institution Calvin was awarded a PhD in 1958 for studies on soil erosion. Teaching physics, and where possible using the agricultural background of the University's students, was a new challenge, as was developing research in agricultural physics (an emerging area of science, and the title of a later innovative textbook, "An Introduction to the Environmental Physics of Soil, Water and Watersheds". Cambridge University Press, 2004, reprinted in 2006). Calvin's research was much assisted by co-operation with agricultural research institutions in East Africa. During this appointment he was a Visiting Scientist with Rothamsted Research Station, UK, and the CSIRO Division of Soils, Adelaide.

Returning to Australia in 1963 for family reasons (and with three children), Calvin joined the Environmental Biology Group of the CSIRO Division of Land Research, a division charged with evaluating the agricultural potential of northern Australia. Soil characteristics were one important factor in this assessment, and Calvin developed a method for determining the hydraulic conductivity characteristics of soil profiles, and the pattern and strategy by which the roots of crops withdraw water. Such information aided the innovative development of computer-based simulations of crop growth and development, an aid in extrapolating likely crop performance to regions remote from the two research stations at Katherine (NT) and Kununurra (WA) where crop experiments were carried out. Crop modelling subsequently became a major research methodology in agricultural science.

In researching crop-atmosphere interactions of heat, moisture and carbon-dioxide, Calvin's research team was able to independently validate the turbulent-exchange theories describing these fundamental exchange processes. His engineering background enabled the development of scientific instrumentation suitable for the rigours of the wet-dry tropics, including an accurate weighing lysimeter which provided a direct accurate measurement of evaporation from a crop within which it was located.

Leaving CSIRO as the Environmental Biology Group leader in 1973, Calvin was appointed by the newly-established Griffith University in Brisbane as the Foundation Dean and Professor of what was then known as the School of Australian Environmental Studies (now Griffith School of Environment). This was the first undergraduate and postgraduate environmental school to be established in Australia; hence developing a curriculum and staff from scratch was a challenging and invigorating task. 'Environmental studies' was designed to provide the knowledge necessary to understand, manage, and hopefully anticipate the consequences of all human activities which have an impact on the natural world, and through that on human well-being and the common good.

As courses developed, Calvin's teaching focussed on management of the soil environment, environmental physics, earth surface processes and environmental modelling, and land and water resources management. Calvin's research initially focussed on regional-scale soil conservation issues, including investigation of management influences on soil erosion and deposition in the Darling Downs using Cs-137 techniques. As it diversified, Calvin's research included supervising 19 PhD and 7 Masters students from a variety of countries including Australia.

On sabbatical leave in 1979 as a Visiting Professor at Texas A&M University and the USDA-ARS Grassland Soil and Water Research Laboratory, Calvin developed a new model of soil erosion/ deposition processes which has been applied in many diverse contexts, and proved to be the best physically-based model of these processes. Rigorous model testing was aided by the design, construction and use of an experimental flume ("Tilting-Flume Simulated-Rainfall Facility") which allows close observation and measurement of erosion in a soil flume subject to any controlled combination of water run-on or simulated rainfall, a facility also used for teaching and by higher degree students to this day. Applications of this model have covered a wide range of agricultural contexts, and also provided the conceptual basis supporting an ARC project and two major ACIAR-funded projects of which Calvin was Director.

Since retiring in 1995, Emeritus Professor Calvin Rose has been collaborating in honorary research with a number of colleagues and PhD students in the Griffith School of Environment. He was appointed Chair of the Fundraising Committee for the proposed Griffith EcoCentre, raising some $2 million to establish the centre on the Nathan Campus. The EcoCentre opened in 2001 as a resource centre promoting sustainable development, leading and encouraging community participation in environmental issues, and, in collaboration with Education Queensland, operates an Education Centre which generates environmental curriculum material and training for Queensland school teachers.

Calvin Rose has been the editor or co-editor of a number of journals, been an invited contributor to many conferences, carried out consultancies for many organisations, and was a member of the Academy of Sciences National Committee for the Environment. He is a Life Member of the Australian Society of Soil Science, a Fellow of the Australian Institute of Agricultural Science and the Institute of Technological Science and Engineering. He has served as a member of the Council of Griffith University, and as a Board Member of the International Soil Conservation Organisation. He was also inaugural Head of the School of Environmental Engineering within the Division of AES (1989-1990), and recalled as Dean of the Faculty of Environmental Studies (1990-93). Calvin has received Honorary Degrees from the Universities of New England and Griffith University, and an AM in the General Division of the Order of Australia (2009). He is currently an Emeritus Professor actively engaged in honorary research with the Griffith School of Environment and its Australian Rivers Institute.

Calvin commenced close involvement with the Royal Society of Queensland in 1978 when he was elected as its President and initiated several symposia. More recently he was one of four editors of "A Place of Sandhills: Ecology, Hydro-geomorphology and Management of Queensland's Dune Islands" *Proceedings of the Royal Society of Queensland, Volume 117* (2011). His interest in these dynamic environments dates back to the 1974 symposium "North Stradbroke Island: A Place for Teaching".

The leadership qualities that Calvin exhibits have led to his high standing. His leadership style is to lead by example with the characteristics of determination, honesty, integrity, enthusiasm and fair play. His leadership in fundraising and planning have led to the construction of the novel Griffith EcoCentre which acts as a community engagement

organisation. In all of this his wife, Mavis, has been a steadfast companion giving support and assistance. Over the 62 years of their marriage she has contributed greatly to his successes.

Calvin's contribution to science and to protective management of our Earth's surface is visible in bricks-and-mortar form at the Griffith EcoCentre, a peaceful and visually appealing building set in bushland at the Nathan campus. But his contribution is spreading more widely, in the intangible form of the knowledge and understanding that his students and their students have gained through his teaching and his mentoring. His legacy in this way will ripple, internationally and throughout Australia, indefinitely. The Society is proud to count him among its distinguished Life Members.

Geoff Edwards
Angela Arthington
Des Connell AM.

The portrait of Calvin Rose was kindly provided by Ms Louise Corke.

ROYAL SOCIETY OF QUEENSLAND, AWARD OF LIFE MEMBER

PROFESSOR RAY SPECHT

INVESTED AS LIFE MEMBER, DECEMBER 2015

Ray Specht was born in Adelaide, South Australia, in 1924. He attended Richmond Primary School, becoming dux of the school in 1937. By the time he entered Adelaide High School in 1938, Ray had developed the goal of becoming a teacher. After completing his Leaving Honours year at Adelaide High School as dux in 1941, Ray pursued his teaching ambition by joining the South Australian Education Department, despite coaxing from one of his teachers to study medicine at university. He was posted in 1942 to Riverton High School to teach physics, chemistry and mathematics. In December 1942, Ray attended a short course at the University of Adelaide designed to introduce teachers to biology. It was organised by Professor Joe Wood of the University's Botany Department.. This experience helped to reset Ray's career compass, so when he began training at Adelaide Teachers College early in 1943, he studied biology, not physics and mathematics as had been his intention. Ray spent four years at the College and the associated University of Adelaide, completing a BSc, majoring in botany and zoology, at the end of 1945, and a BSc Hons (First Class) in plant ecology at the end of 1946, besides various subjects toward an unfinished Diploma of Secondary Education.

In September 1946, Ray was called into Professor Wood's office to meet Charles Mountford, who wanted a botanist to accompany him on a planned expedition to Arnhem Land, due to depart early in 1947. The opportunity was irresistible, and Ray obtained leave from the Education Department, frantically finished his Honours project, and prepared for the expedition. Ray and the fifteen other members of the expedition eventually departed from Adelaide in March 1948. Ray was its youngest member. The team was in the field for 8 months and gathered 25 tonnes of specimens. The indefatigable Ray collected over 13,500 plant specimens filling 42 crates.

The work continued after the expedition, identifying specimens and preparing them to be distributed to six herbaria in Australia, Kew in England, the Rijksmuseum in Leiden (initiating the *Flora Malesiana*), and the Smithsonian Institution and Arnold Arboretum in the United States. Ray spent the first half of 1949 in Queensland, working with Stan Blake, Selwyn Everist, Cyril White, Bill Francis and Lindsay Smith. Ray went on to have a major role in writing up much of the Arnhem Land work, finishing in 1964 with the publication of the zoological material on behalf of Dave Johnson. His understanding of the relationship between the biota and the landscape across space and time was deepened.

On his return from Arnhem Land, Ray joined the Botany Department as a senior research fellow. He was awarded an MSc early in 1950, based on work prior to the Arnhem Land interruption, and he subsequently enrolled in a PhD, studying mineral nutrition and biomass relationships of the heath vegetation at Dark Island on the ancient dunes of south-eastern South Australia. He was appointed lecturer in botany in 1951. Ray's work for his PhD, conferred in 1953, was the start of his eventual global pre-eminence in the nature and dynamics of sclerophyll vegetation as evidenced by his editorship in 1979 and 1981 of the 'Heathlands and Related Shrublands' volumes in the 'Ecosystems of the World' series, published by Elsevier. This includes definitive analyses of semi-arid heathlands in southern Australia, the chaparral lands in south-western United States, and garrigue in southern France. He received Fulbright, Smith-Mundt

and Carnegie grants in 1956, a Royal Society Nuffield Foundation Commonwealth Bursary in 1964, and a Fulbright Senior Scholar Award in 1983, for studies in the USA, the United Kingdom, and the USA, respectively. In 2000, Ray was named as an IBC Outstanding Intellectual of the 20th Century.

Ray's academic career spanned three universities: Adelaide (1951-1960), Melbourne (1961-1965) and Queensland (1966 to 1989). He was invited to join the Botany Department at the University of Melbourne as a Reader in 1961, and in 1966 moved to Brisbane, succeeding Des Herbert as Professor of Botany at the University of Queensland. He has always been passionate about teaching, both at universities and at high schools. He was an early contributor to and champion of the 'Web of Life' program, which was developed for Australian high schools in the late 1960s from the innovative Biological Sciences Curriculum Studies program in the United States of America. It emphasised the 'learning by doing' approach to teaching, demonstrably better for student understanding and retention, but often a challenge for educators! He and wife Marion brought the Web of Life to high schools in Queensland. At university, he emphasised the importance of discovery through fieldwork, and developed a strong eco-physiological approach, establishing significant research and teaching programs, including research and teaching at North Stradbroke Island (e.g. 'The Vegetation of North Stradbroke Island' with Trevor Clifford and Marion Specht (1979), and numerous papers and articles including 'Stradbroke Island: a place for teaching biology' (1975)).

Ray has been a pioneer in the application of digital technologies to science, particularly in the determination and assessment of native biota. In this he was ahead of his time as a 'Big Data' innovator. In 1974 he and two colleagues at the University of Queensland, Ethel Roe and Valerie Boughton, steered a project to assess the conservation status of plant communities (as a proxy for ecosystems) in Australia, which became known commonly as the Specht Report (Specht et al. 1974). Through this, it became apparent that 'facts' were insufficient, and were poorly collated and difficult to access: Specht et al. relied upon expert opinion, clearly dependent on the personal expertise of the people reporting at the time. So he launched a project that is still going today, to gather and deliver the evidence required. This was a bigger job than he thought, taking 20 years to discover, extract and analyse the data, at a time when this was considered rather 'outre'. Now whole issues and strands of the journals 'Nature' and 'Science' are devoted to the importance of reliable and historical 'real' data for science. Today Ray's data, collected and stored in old technologies, are being upgraded for delivery through the Atlas of Living Australia and the Terrestrial Ecosystem Research Network. This will enable plot data from the 1860s to 1995 to be easily discovered, making long-term monitoring more achievable. After retirement, Ray has taken great pleasure as a scientific adviser for Queensland's Statewide Landcover and Trees Study (SLATS).

Ray has published more than a dozen books, more than 80 book chapters, and many articles in refereed journals, on plant ecology and conservation. One of his publications, containing his structural classification of Australian vegetation, was for many years (and may still be) the most cited publication in the Australian scientific literature. Major publications include 'The Vegetation of South Australia' (1972); 'Conservation of Major Plant Communities in Australia and Papua New Guinea' (1974); 'Heathlands and Related Shrublands of the World' (1979, 1981); 'Mediterranean-type Shrublands' (1981); 'Mediterranean-type Ecosystems' (1988); 'Conservation Atlas of Plant Communities in Australia' (1995); and the academic textbook 'Australian Plant Communities: Dynamics of Structure, Growth and Biodiversity' (1999, 2002). The latter two titles were undertaken in retirement with daughter Alison.

Former student Dr Jim Davie has observed: 'Ray realised, and then made his own, the understanding that the big element that defined Australia's plant ecology was water; and that the species focus, upon which so much plant ecology was and remains focused, was a colourful distraction. This would only be understood once variation in the structure of the plant communities could be comprehended.'

'Importantly, Ray has consistently promoted the conservation of Australia's diverse vegetation for 50 years. His work "Conservation of Major Plant Communities in Australia and Papua New Guinea" with others in 1974 and his report in 'A National System of Ecological Reserves in Australia' (in Fenner, ed., 1975, Australia Academy of Science Report No 19) were among the earliest attempts to promote conservation based on the systematic classification of vegetation communities on a

continental scale. He has tirelessly sought to understand vegetation pattern through the study of soil fertility and ecosystems and through computer classification of species assemblages.'

Ray Specht has been active in the Society and in science to this day. In 2017 he will celebrate fifty years as a Member of The Royal Society of Queensland. He can also take comfort in noting that his work has not been relegated to the archives of professional journals. His article 'American-Australian Scientific Expedition to Arnhem Land (1948): Its Long-Range Impact', published in 'The Open Ecology Journal' in 2012 at the age of 88, described the long-lasting influence of the 1948 expedition, including observations on the diet of the Indigenous inhabitants, a matter of profound contemporary significance.

Alison Specht
Paul Sattler OAM
Ross Hynes
Jim Davie
Brett Stubbs

OBITUARY OF ROBERT WILLIAM (BOB) JOHNSON
1930 - 2012

Robert William Johnson was born at Newmarket, Brisbane to parents Leonard and Lotti-Rose. It is reported that as a boy he developed an early interest in morning glories in the back yard of his home. This laid the foundation for his focus on botany and the family *Convolvulaceae* later during his professional career, among many other things.

Bob attended Brisbane Grammar School and achieved academically and on the sporting field. However he was reluctant to display any signs of his achievements, to the extent that his parents would find award certificates in his wastepaper bin. This manifestation of his humility and a focus on the other person would remain throughout his life. He was so tuned in to what other people were saying to the extent that he became more interested in their accounts than they were themselves.

He joined the Qld Department of Agriculture & Stock (later Qld Department of Primary Industries) as a cadet in 1948, while studying part time for a BSc in botany and soil science at the University of Queensland. He graduated in 1953 and was appointed botanist at the Botany Branch and Queensland Herbarium, where he worked on many research projects before embarking on the ecological survey of brigalow lands.

Bob earned his nickname 'Brigalow Bob' when undertook the brigalow survey from 1958 to 1962. He inspected every accessible patch of brigalow in the state and visited many landholders who had never seen a QDPI officer on their properties. Bob developed strategies for the clearing of brigalow country, prevention and control of brigalow regrowth and sound agricultural and pastoral systems. This underpinned Queensland's best land development scheme: the Fitzroy Basin. Bob was instrumental in the selection and establishment of the Brigalow Research Station at Theodore to conduct research to support the brigalow scheme.

He met his wife Toni at the Herbarium in 1959 and they married in1962. Later that year he was appointed Officer-in-Charge of the newly established Brigalow Research Station, where the family moved with their first child. He completed his MSc on the ecology of brigalow in 1963.

The Johnson family moved to Logan, Utah, USA for four years in 1970 for Bob to undertake his PhD in multivariate methods for the analysis of botanical data under David Goodall, on a scholarship from the Australian Wool Board. When Bob returned to Australia in 1974 he was appointed Assistant Director, Botany Branch (Queensland Herbarium) to Selwyn Everist, succeeding Selwyn as director in 1976.

Bob was a multi-skilled botanical scientist and his expertise extended over many areas. His main interests were the ecology and control of brigalow (*Acacia harpophlla*), the design and maintenance of databases, a taxonomic specialist in the morning-glory family Convolvulaceae (in which he described 28 new taxa), a talented manager of research institutions and scientific staff and the conservation of plants and animals.

He published widely in all these fields more than 90 publications. These include scientific papers, books and book chapters in ecology, taxonomy, biographical, managerial, weeds and conservation (43), taxonomy (20), biographical (7), managerial (7), weeds (5), conservation (2). He collected widely with 5000 herbarium specimens from throughout Australia including 4000 from Queensland. He is recognised by the following Queensland species that were named in his honour: *Acacia johnsonii, Commersonia johnsonii, Paspalidium johnsonii, Psydrax johnsonii* and *Solanum johsonianum*.

He had a major role in the early stages of databasing the 600,000 specimens of the Queensland Herbarium (HERBRECS), at that stage being only one of two major world herbaria to have databased their label information. During his 14 years as Director, the three volume *Flora of South-eastern Queensland* was published as were a number of vegetation surveys and mapping reports.

Bob's managerial skills were widely recognised by his being appointed Officer-in Charge of the Agricultural Research Laboratories at Indooroopilly (1984-1990), and by his position as presidents of two Australian scientific societies (Royal Society of Queensland (1981-1982) and the Ecological Society of Australia (1985-1986). He was also instrumental in the founding of the Federation of Australian Scientific and Technological Societies (FASTS) (board member 1986-89) to improve the profile of scientists in Australia. He was also an active member of CHAH (Council of the Heads of Australasia Herbaria), ASBS (Australasian Systematic Botany Society), the Bridled Nailtail Wallaby Recovery Team, the Scientific Advisory Committee for the Nature Conservation Act, Chair of the Protected Plants Management Advisory Committee and Chairman of Public Library Review Consultative Committee (1991).

He continued to work on his projects at the Queensland Herbarium for the 22 years since his retirement, often coming to the Herbarium a couple of days a week. He had 17 unfinished projects upon retirement, and although he has completed some of these, he did commence others. His dedication to thorough ecological scientific research is reflected in the continual monitoring of a transect of his 'beloved' brigalow woodland at the Brigalow Research Station for 46 years, the last of which was undertaken during a heatwave a couple of years ago. On the taxonomic front work was continuing on the study of Australian Convolvulaceae and at the time of his death there were still loans arriving from other herbaria to be studied by Bob.

Bob will be best remembered for his contribution to the Queensland Herbarium, and for passing on its traditions and adding to them. Bob was a kind and considerate person who had many talents – his upbeat, positive, cheerful, encouraging, energetic approach to life and botany, his mentoring and willingness to share his wealth of knowledge, including invaluable advice to all the exotic places he and Toni visited in recent years. He had a wide knowledge on many things and would readily discuss with enthusiasm subjects ranging from Australian Rules Football to the intricacies of a Mahler symphony.

Bob is survived by his wife Toni and their children, Brett, Kim and Jodie and their families.

Gordon Guymer
Bryan Simon

New taxa described by R.W. Johnson

Taxon	
Bonamia alatisemina R.W.Johnson	new species
Bonamia deserticola R.W.Johnson	new species
Bonamia erecta R.W.Johnson	new species
Convolvulus angustissimus subsp. ***omnigracilis*** R.W.Johnson	new subspecies
Convolvulus angustissimus subsp. ***peninsularum*** R.W.Johnson	new subspecies
Convolvulus eyreanus R.W.Johnson	new species
Convolvulus graminetinus R.W.Johnson	new species
Convolvulus microsepalus R.W.Johnson	new species
Convolvulus recurvatus R.W.Johnson	new species
Convolvulus recurvatus subsp. ***nullarborensis*** R.W.Johnson	new subspecies
Convolvulus tedmoorei R.W.Johnson	new species
Convolvulus wimmerensis R.W.Johnson	new species
Davenportia R.W.Johnson	new genus
Duperreya halfordii R.W.Johnson	new species
Ipomoea antonschmidii R.W.Johnson	new species
Ipomoea argillicola R.W.Johnson	new species
Ipomoea bracteolata R.W. Johnson	new species
Ipomoea densivestita R.W. Johnson	new species
Ipomoea dunlopii R.W. Johnson	new species
Ipomoea funicularis R.W. Johnson	new species
Ipomoea kalumburu R.W. Johnson	new species
Ipomoea limosa R.W. Johnson	new species
Ipomoea polpha R.W.Johnson	new species
Ipomoea polpha subsp. ***latzii*** R.W.Johnson	new subspecies
Ipomoea polpha subsp. ***weirana*** R.W.Johnson	new subspecies
Ipomoea saintronanensis R.W.Johnson	new species
Ipomoea tolmerana R.W. Johnson	new species
Ipomoea tolmerana subsp. ***occidentalis*** R.W. Johnson	new subspecies
Ipomoea versipellis R.W. Johnson	new species
Merremia kimberleyensis R.W.Johnson	new species
Convolvulus angustissimus subsp. ***fililobus*** (Wawra) R.W.Johnson	new combination
Davenportia davenportii (F.Muell.) R.W.Johnson	new combination
Operculina aequisepala (Domin) R.W.Johnson	new combination
Stictocardia queenslandica (Domin) R.W.Johnson	new combination

BOOK REVIEW:
FRESHWATER RESOURCES OF THE TROPICAL NORTH OF AUSTRALIA: A HYDROBIOLOGICAL PERSPECTIVE

Dilwyn J. Griffiths (2016)
Nova Science Publishers, Inc., New York
ISBN: Hardcover 978-1-63484-808-4 (209 pages)
ISBN E-Book 978-1-63485-007-0

The tropical north of Australia has for a long time attracted the attention of those seeking new frontiers for development. Central to this has been the development of the vast freshwater resources that in some eyes have been seen as needing to be harnessed before they drain away to the coasts and beyond to the oceans to be wasted. Such views have been part and parcel of our national view on developing our freshwater resources, including the vast amounts that occur across northern Australia. The development of our freshwater resources has attracted a great deal of attention and has been at the forefront of many schemes to develop our rural industries and support our highly urbanised society. Nowadays we hear more about the need to restore the freshwater ecosystems that have been drastically changed as a consequence of such development.

Northern Australia has vast freshwater resources and there is considerable public debate about how these can be developed, with an increased emphasis on sustainability and avoiding the mistakes made in the past in the south. That discussion has a long way to go and can now be better informed by the publication of this book. We now have a book that provides an overview of the freshwater resources, including the major developments that have occurred, in Australia's north. It addresses the major developments that have occurred with the construction of major water storages and water-related infrastructure following World War II and leading to the more recent developments with their increasing emphasis on sustainability and protection of the environment. The author is well placed to write this book given that he was appointed to the Chair of Botany at James Cook University, Townsville, Australia in 1974 and remained there until his retirement in 1997, when he was appointed Professor Emeritus at the same University, and moved to Brisbane.

Many readers may have a general knowledge about the water resources in northern Australia – the book provides the information that is needed to understand and inform decision making about these resources. It reports that 70% of Australia's total freshwater resource is in northern Australia, with Queensland contributing about 45% of Australia's surface run off, with most of this in the northern drainage basins. Then you have the drainage basins in the Northern Territory and in the north of Western Australia. An important feature of this resource is that most of it comes during the December to March wet season. The northern-draining catchments cover approximately 17% of the land area of mainland Australia but generate over 60% of the continent's surface water run-off, with less than 2% of its population. These are not only fascinating figures but also indicate the issues facing those who plan to develop the north in a sustainable manner.

The book focuses on the more recent work, but refers extensively to earlier information to provide a more expansive background to more recent work; in doing this it contributes to the undoubted knowledge and wisdom that already exists. The extensive literature that abounds is brought together and provides a thorough and very readable account of the freshwater resources in what amounts to a series of case studies. These extend across the north and includes analyses of information from the Fitzroy river basin in Queensland northwards to Bowen-Mackay, the Burdekin river and further north to the wet tropics of northern Queensland, then across Cape York to the Gulf country and Mount Isa, and into the inland arid zone, and the tropical floodplain systems of the Northern Territory and then the Ord river and the Kimberley and Pilbara in Western Australia. This is a lot of country and represents an immense freshwater resource. The key message from the text is that a lot of research has been done and published. Having

worked across some of these regions and reviewed the literature a number of times over the past decades I'm very aware that this is a huge effort and provides us with an unparalleled overview of these resources. There are gaps in the information base but anyone currently working across northern Australia would do well to consider what is presented in this book.

Given the scope of the overview, my attention was drawn to two areas that I know particularly well, but from different eras. The story about the water resource development and management in the Mount Isa area provides a case study of an isolated mining community, including the contribution made by the mining company in collaboration with others. The story of Lake Moondarra on the Leichhardt river is fascinating with the water quality issues of a lake located downstream of a major mine and city coupled with the management of aquatic weeds, and the efforts to maintain a clear domestic water supply. Further to the north there is the magnificent engineering structure that impounds Lake Julius and the subject of some intriguing cyanobacterial studies in the 1990s. There are lessons in these established ventures for other resource developments. Then there is the extensive research effort that has occurred in Kakadu National Park where the political manifestations of uranium mining, indigenous land ownership and nature conservation conspired to produce possibly the most intensive freshwater investigations in northern Australia, focussed on Magela creek. The information base from these efforts now spans 4 decades, something that does not characterise a lot of other such projects across northern Australia. There are impressive investigations across other systems, including the Cooper Creek and Ord River and Kimberley, but the breadth and length of the Kakadu effort surely stands out in its detail as much as it should be a model for others.

The information compiled in this book is impressive and unparalleled for Australian freshwater systems outside of those in the temperate south. This alone makes the book a critical resource and something that should be read and re-read as others seek to understand the freshwater resources of tropical Australia. And when you have finished working through the text you have access to a comprehensive reference list, and a very useful index. All this combined convinces me that this book represents the best available resource we have for freshwater resources in northern Australia. Anyone interested in this subject needs to get a copy – it will certainly short-cut their efforts to come to grips with the literature and knowledge that is available.

With that endorsement in mind I'd like to thank Emeritus Professor Griffiths for compiling this treatise, and to also recognise the support he has provided to many of the authors listed in the bibliography, including myself starting in the mid-1970s when I made my first venture into northern Australia and started to come to grips with its freshwater resources. How I would have loved to have had access to this book.

AUTHORS PROFILE

MAX FINLAYSON, THE REVIEWER

Director Institute for Land, Water & Society & Professor for Ecology & Biodiversity, Charles Sturt University, Albury, Australia

Ramsar Chair for the Wise Use of Wetlands, UNESCO-IHE, Institute for Water Education, Delft, The Netherlands

Visiting Research Professor, Institute for Wetland Research, Chinese Academy of Forestry, Beijing, China

Editor-in-Chief, Marine and Freshwater Research, CSIRO Publishing

DILWYN GRIFFITHS, THE BOOK AUTHOR

Present position: Professor Emeritus, James Cook University, Townsville, Australia.

Dilwyn Griffiths, born in 1932, was brought up in a rural farming community in west Wales. A graduate of the University of Wales, his post-graduate (Ph.D) training specialised in studies of the growth and metabolism of microalgae. After a short period as a High-school teacher in Cardiff, he was appointed Assistant Lecturer (later Lecturer) in Plant Physiology at the University College of North Wales, Bangor. In 1967 he was appointed Senior Lecturer at the newly-established La Trobe University, Melbourne, Australia and in 1974 was appointed to the Chair of Botany at James Cook University, Townsville, Australia. On retirement in 1997, he was appointed Professor Emeritus at the same University, but now lives in Brisbane.

He is the author or co-author (with colleagues or as supervisor of post-graduate research programs) of publications dealing with various aspects of the biology of marine and freshwater microalgae and with studies of the freshwater resources of the tropical north of Australia. Since his retirement, he has continued to write reviews and has taken an active interest in current developments in his area of biological research. He is the author of two books previously published by Nova Science Publishers:- Microalgal Cell Cycles (2010), Microalgae and Man (2013).

He is a Fellow of the Royal Society of Biology, UK and a long-term member and supporter of the Royal Society of Queensland.

Dilwyn and his wife Elen, who is also a graduate of the University of Wales, have two daughters and a son and eight grandchildren – all living in Australia.

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